REHEATING AND COMPACTION TEMPERATURE OF HOT MIX ASPHALT

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Declaration

I hereby declare that this thesis entitled “REHEATING AND COMPACTION TEMPERATURE OF HOT MIX ASPHALT.**”** was composed by myself, with the guidance of my advisor, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or processional qualification. Parts of this work have been published in [state previous publication.

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Certificate

This is to certify that the thesis prepared by **Mr. Tamirat Dushe Benti** entitled "**Reheating and Compaction Temperature of Hot Mix Asphalt.”** and submitted in fulfillment of the requirements for the Degree of Master of Science complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

Different studies discussed about the effect of temperature on hot mix asphalt and found significant effect on the performance of asphalt concrete pavement.

This study was intended to investigate the effect of reheating and remolding on the hot mix asphalt tested at different cooling time and effect of temperature on the asphalt pavement road compaction also evaluated and analyzed by compacting the Hot Mix Asphalt at different compaction temperature and the difference has been studied with reference to the normal Marshall Mix Design preparation procedures.

The effect of temperature on compaction of hot mix asphalt has been studied at different compaction temperature starting from 60°C to 160°c in the laboratory. While the effect of reheating is studied by cooling the HMA at different cooling hours 0Hrs, 5Hrs, 12Hrs and 24Hrs and reheating to a compaction temperature.

The test result shows that temperature does have an effect on the compaction asphalt and on the performance of the paved asphalt road. This thesis presents the statement of the problem, objectives, literature review; test methodology of Design Analysis and evaluation of effects of temperature on the hot mix asphalt in accordance to the most commonly used Hot Mix Asphalt Concrete Mix Design Methods used in Ethiopian highway Roads.

From various mix design methods of hot mix asphalt Marshal Mix design is a default method in Ethiopia. Even if this mix design methods performed considering actual traffic flow, actual weather condition, reliable expected compaction and compaction methods, Design aggregate structures, Design

Asphalt binder content it is observed that some roads are failed to serve for the required design period.

Therefore, evaluating and analyzing the mix design method in use considering the actual condition will increase the performance period of the road, minimizes unwonted periodic maintenance and damage of the road. The ultimate goal of this thesis is to analyze and evaluate the temperature of hot mix asphalt design method, and recommend some conditions that have to be kept in mind while preparing mix design and working with hot mix asphalt.

Accordingly, 22 samples are prepared to analyze the compaction temperature of hot mix asphalt, to be compacted at different compaction temperature and the figured effect is significant. Whereas 10 samples are also analyzed for the effect of reheating and remolding which practiced at different cooling temperature and the result is found to be significant.

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List of Abbreviations

ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
HMA	Hot Mix Asphalt
TFV	Ten Percent fines Value
LAA	Los Angeles Abrasion
PSV	Polished Stone Value
TRL	Transport Research Laboratory
AASHTO	American
AADT	Annual Average Daily Traffic
ASTM	American Society for Testing and Materials
AASHTO	American Association of State Highway and Transportation Officials
CBR	California Bearing Ratio
TRL	Transport Research Laboratory
BS	British Standard
PI	Plasticity Index
RTFOT	Rolling thin Film Oven Test
Pa.s	Pascal Second
DBC	Design Bitumen Content
VIM	Void in Mix
VFB/VFA	Void Filled with Bitumen/Asphalt
VMA	Void In mineral aggregate
BSG	Bulk Specific Gravity
G_{mm}	Mixture maximum Specific Gravity
ERA	Ethiopian Roads Authority

Chapter 1

Introduction

1.1 General

Asphalt is dark brown to black, highly viscous, hydrocarbon produced from petroleum distillation residue. This distillation can occur naturally, resulting in asphalt lake, or occur in a petroleum refinery using oil.

Hot mix asphalt is a combination of approximately 95% of stone bound together by asphalt at high mixing temperature used for pavement road construction. Among different proportioning of Asphalt and aggregate; Marshall Mix design method is widely used in Ethiopia.

Marshall Mix design method was introduced by Marshall Bile since 1950 on the Second World War in order to forecast the heavy traffic flow utilized for the war. Most of the HMA (Hot Mix Asphalt) produced during the 50 years between the 1940th and mid 1990's were designed using the Marshall or Hveem methods in USA. In our country currently, this hot mix asphalt is widely used in a pavement design.

Even though, Billions of the country's' birr is invested to build hot mix asphalt road projects annually, the educational background or researches conducted on hot mix design preparation and application of asphalt road is not satisfactory.

However Asphalt road mix design preparation and application is not included in the curriculum of higher educational institutes, now a day several roads are under construction.

Due to this information gap, it is clearly seen that defects like cracks, bleedings, and difficulty to achieve the design period and allocating huge amount of money for periodic maintenances of performing road.

The purpose of this study is to describe the production and placement of asphalt mixture from a practical point of view.

Most importantly the study shall be expected to fill the gaps that are practicable usually. Especially this study is concerned on the effects of temperature on hot mix asphalt during preparation of mix design and laboratory evaluation of the mix after and/or before placement of the asphalt.

Temperature is the core point when you are working with hot mix asphalt to assure the targeted quality. Due to different reasons the temperature of hot mix asphalt might not be maintained for long time and the mix is subjected to cooling before compaction or placement of the material.

Therefore, it is necessary to know the effects of temperature on hot mix asphalt by running different testes on cooled mix and comparing with the prepared mix design as per the Marshall manual.

Accordingly, the effect of reheating and remolding was studied at four different samples with different testing time, by letting the asphalt mixture sample to be cooled below compaction temperature and reheating to compaction temperature the effect of temperature by reheating and remolding was investigated and studied.

In the same manner compaction temperature also studied by different eleven samples compacted at a different compaction temperature and the achieved compaction temperature was studied and compared with standard compaction temperature.

Temperature has a vital value in a controlling the quality of the work especially during placing and compaction.

Basically there are different parameters that are related with temperature and some of them are listed here under:

- ✓ Reheating and remolding of asphalt sample.
- ✓ Mixing and Placement temperature.
- ✓ Compaction temperature.
- ✓ Weather condition or seasonal condition of paving temperature
- ✓ Selection of asphalt grade and topographic location

From this temperature related points this study focused on compaction temperature and on reheating and remolding of hot mix asphalt.

Therefore, this thesis deals with the effects of temperature on HMA (Hot Mix Asphalt) during preparation of the mix, placement of the mix and compaction temperature of the mix. Most importantly this thesis focused on quality control crew judgment.

This paper comprises of literature review, research methodology, test result collection and evaluation and finally conclusion and recommendation.

1.2 Problem Statement

The problem statement of this thesis is mainly focus on the problem happen due to knowledge gap of HMA mix design method. Especially concerning temperature of hot mix asphalt there are different problems on the roads and public transport users' mobility has been seen.

Temperature of hot mix asphalt is a core thing in asphalt mix paving and during transportation of the mixed asphalt from asphalt plant to paver there might be long time driving and different problems might be happened on the track, due to this transportation problem the temperature of the mixed asphalt might be dropped to less than compaction temperature and if this cooled asphalt is paved the following problems might be happened

- ✓ **Longitudinal and lateral crack of high way roads (rutting and crack)**

Different problems will cause rutting and cracks among those rutting problem can be occurred especially when the compaction temperature of HMA is not practically achieved.

Cracks on the pavement asphalts have been seen and the reasons for these problems are not achieving the percent of compaction, drop of temperature before compaction, over compaction, and improper compaction. In several places longitudinal cracks are observed due to jointing problems.

Figure 1.1. Longitudinal rutting

- ✓ **Bleeding and shrinking of pavement surface road.**

The effect of temperature on hot mix asphalt is sometimes shown as bleeding structure road. Bleeding is shining black surface film of asphalt on the road surface caused by upward movement of asphalt in the pavement surface. Common causes of bleeding are too much asphalt in asphalt concrete, hot weather, low space air void content and quality of asphalt.

In this case if the asphalt pavement is over compacted, the asphalt pavement might not have enough space for air voids to expand in hot weather condition.

Figure 1.2. Bleeding with rutting

- ✓ **Difficult to achieve the design period of performing pavement road.**

It is clearly seen that most of our roads are failed to achieve the design period. This difficulty is mainly due to knowledge gap, since our higher educational institutions are not covering and mostly the road engineers are self-learning on the project under construction. Additionally the researches done on this HMA are very limited.

Figure 1.3. early failed asphalt pavement road

- ✓ **Redundantly allocating huge amount of money for periodic maintenances**

Since the pavement roads are not achieving their design period, the government is forced to allocate huge amount of money for maintaining the pavement roads.

Figure 1.4. periodic Maintenance of pavement Road

- ✓ **Cause for traffic accidents especially for public transport users mobility and safety while unselecting the deteriorated pavement road.**

In so many places while driving on the deformed road there might be some selection of roads for riding comfort and this might be a main cause for the traffic accident. Mostly this type of traffic accident is happened when the drivers drive on the shoulders, walkways, opposite directions of the road to gain the riding comfort.

1.3 Research Objective

The general objective of this thesis is to evaluate the most commonly used HMA for better performing road relating to the temperature by re-heating and compaction of the mixture.

The Specific objectives of the project are:

- To study the effect of reheating and remolding asphalt concrete.
- To study the compaction temperature of asphalt.
- To study Marshal Property of HMA mixes.

1.4 Scope and Limitation

This thesis is limited to temperature; and it is conducted due to effects of temperature variation and compaction temperature there will be pre mature fail of asphalt pavement road. Accordingly the main scope of this thesis is limited to investigating the effect of temperatures on hot mix asphalt by studying

1. The effect of reheating and remolding of asphalt concrete if the temperature of hot mix asphalt is cooled before compaction or during operational condition. This reheating and remolding effect is mainly applicable for laboratory tests because the hot mix asphalts samples are collected from asphalt plant or paving place, and when the samples arrived to lab it might be cooler than the compaction temperature. Therefore, the sample is going to be reheated and remolded to gate the lab results. In this case when the sample is reheated and remolded the properties of asphalt might be affected and the test result will not be trust. Now the scope of this thesis is to find out the effect of reheating and remolding on the test results.

   The thesis is also limited to lab test only while the material is sampled from site and prepared on laboratory for this thesis the material is going to be cooled to different temperature and reheated. The sample is going to be cooling temperatures are different by zero hours, five hours, 12 hours and 24 hours. Then the cooled hot mix asphalt shall be reheated to compaction temperature. By running different laboratory tests and comparing those results with normal procedure the effects shall be investigated.

2. The compaction temperature is the basic parameter during paving asphalt concrete, the study of the effort of compaction temperature is limited to lab test only.

   When the material is subjected to cooling due to different reason the mixed asphalt concrete might be used or rejected. Therefore, it is necessary to study the compaction temperature by compacting at different temperature starting from 60oC to 160oC. By running different lab tests and comparing with normal procedure the effect of temperature on compaction shall be investigated.

All the results are presented in the study based on the laboratory experiment and not verified practically. Finally, from the test study different conclusions and summary are prepared including a recommendation.

Chapter 2

Literature Review

2.1 General

HMA wearing courses are the most critical layer in a pavement structure and must be of high quality and have predictable performance. Typically HMA wearing courses need to possess the following characteristics:

i. high resistance to deformation;

ii. high resistance to fatigue and the ability to withstand high strains i.e. they need to be flexible

iii. sufficient stiffness to reduce stresses in the underlying layers to acceptable levels;

iv. high resistance to environmental degradation i.e. good durability;

v. low permeability to prevent the ingress of water;

vi. good workability to allow adequate compaction to be obtained during construction;

vii. sufficient surface texture to provide good skid resistance in wet weather; and

viii. Predictable performance. (Overseas Road Note 19 ;2002)

Mixture were designed in the laboratory using a maximum compaction effort in an attempted to produce densities in the laboratory which were similar to those achieved in the field under construction and simulated aircraft loading (Freddy L. Roberts, Prithvi S. Kandhal, E. Ray Brown 1996).

Asphaltic concrete (AC) is a dense, continuously graded mix which relies for its strength on both the interlock between aggregate particles and, to a lesser extent, on the properties of the bitumen and filler. (ERA Design manual 2002).

2.2 Aggregate Quality Test to be used in HMA

Aggregate for HMA is usually classified by size as course aggregate, fine aggregate, or mineral filler. ASTM defines coarse aggregate as particle retained on No. 4 (4.75 mm) sieve, fine aggregate as that passing No. 4 sieve (4.75 mm) and mineral filler as material with at least 70 percent passing the No. 200 (75µm) sieves (Freddy L. Roberts, Prithvi S. Kandhal, E. Ray Brown 1996).

Aggregate is the major component in HMA and the quality and physical properties of this material have a large influence on mix performance. Typically the qualities required of aggregates are described in terms of shape, hardness, durability, cleanliness, bitumen affinity and porosity. In addition to these properties, the micro texture of the aggregate particles will also strongly influence the performance of a compacted HMA layer. (Overseas Road Note 19; 2002)

2.2.1 Shape

Aggregate particle suitable for use in HMA should be cubical rather than flat, thin or elongated. (Hot Mix Asphalt Paving Handbook, 2000)

a. Flakiness index determined in accordance BS 812 part 105.1

It is necessary that coarse aggregates used in bituminous mixtures have a satisfactory shape and the material must be cubical rounded and not flaky. The Flakiness Index is determined for material passing a 63mm sieve and retained on a 6.3mm sieve. The index represents the percentage of the aggregate whose least dimension is less than 0.6 times the mean dimension of the aggregate (Overseas Road Note 19; 2002).

b. Aggregate angularity

A high value of angularity (i.e. more cubical) of both coarse and fine aggregate should produce high levels of internal friction and rutting resistance. Coarse Aggregate Angularity is defined as the percentage by weight of aggregates larger than 4.75mm with one or more fractured faces. Fine Aggregate Angularity is defined as the percentage of air voids in loosely compacted aggregate smaller than 2.36mm (Overseas Road Note 19; 2002).

c. Flat and elongated aggregate particles as per BS 812 part 105.2

This characteristic is similar to the flakiness index and is considered important because flat and elongated coarse aggregates are liable to break, either during construction of the pavement or later under traffic. It is defined as the percentage by mass of aggregate (material larger than 4.75mm) that has a maximum to minimum dimension ratio greater than five present (Freddy L. Roberts, Prithvi S. Kandhal, E. Ray Brown 1996).

2.2.2 Hardness

This Hardness defines the strength or toughness of aggregate particles and can be measured by four tests that are used to establish the ability of an aggregate to resist crushing and impact during road construction and subsequent service life. All four tests are carried out on coarse aggregate particles between 14mm and10mm only (Overseas Road Note 19; 2002).

a. Aggregate Crushing Value (ACV) as per BS 812 part 110

In this test a fixed crushing force of 400kN is applied gradually to the coarse aggregate sample contained within a mold. The ACV test result is reported as the amount of fines produced passing the2.36mm sieve, expressed as a percentage of the initial sample weight. The test is not suitable for weaker aggregates (Freddy L. Roberts, Prithvi S. Kandhal, E. Ray Brown 1996).

b. 10% Fines Aggregate Crushing Test (TFV) (BS 812 part 111)

This test is a development of the ACV test and uses the same apparatus. Samples are crushed under a range of loads so that the load which produces 10 percent of fines finer than 2.36mm can be determined. An advantage of the test is that it can be used with all aggregates irrespective of their strength, thus enabling direct comparisons to be made between strong and weak materials (Freddy L. Roberts, Prithvi S. Kandhal, E. Ray Brown 1996).

c. Aggregate Impact Value (AIV) as per BS 812 part 112

In this test a coarse aggregate sample is subjected to successive blows from a falling hammer to simulate resistance to impact loading. After testing, the AIV is the amount of material finer than 2.36mm expressed as a percentage of the initial sample mass. The test was designed to be supplementary to the ACV test for values up to 26.Softer aggregate should be tested using a modified procedure to ensure that the generation of excessive fines does not invalidate the result (Tanzania Laboratory Testing Manual; 2000).

d. Los Angeles Abrasion (LAA) (BS 812 part 113)

In this test an aggregate sample is subjected to scratch and impact by steel balls while rotating within a steel cylindrical drum at a prescribed rate for a set number of revolutions. On completion of the test, the sample is screened on a1.70mm sieve. The coarser fraction is washed, oven dried and weighed. The loss in weight expressed as a percentage of the original sample weight is the Los Angeles Abrasion Value (Taylor and Frances Group; 2006).

2.2.3 Durability

Durability is measured with reference to either mechanical deterioration or a combination of mechanical and physicochemical deterioration. In the first case it is assessed by abrasion tests in the second by soundness tests. The value of abrasion is used not only for the interpretation of the aggregate strength quality (Tanzania Laboratory Testing Manual; 2000).

a. Polished Stone Value (PSV) (BS 812 part 114)

This is a predictive measure of the durability of aggregate used in wearing course sand surface dressings to polishing under traffic and hence increases the risk of wet skidding at low speeds. The recommended value of PSV depends on traffic levels and site characteristics (Overseas Road Note 19; 2002).

b. Water absorption

High water absorption in aggregates usually indicates low durability and can also cause problems during HMA design. It can be routinely determined as part of the procedure to measure the relative densities of the various size fractions of aggregate since it is the difference in mass between saturated surface dry and oven dried aggregate expressed as a percentage of the oven dried sample mass (Taylor and Frances Group; 2006).

c. Soundness - sodium or magnesium test

This test can be carried out on both coarse and fine aggregate and they estimate the degree of resistance of the aggregate to in-service weathering. An aggregate sample is exposed to, normally, five cycles of immersion in a saturated solution of either sodium or magnesium sulphate followed by oven drying. The result, calculated from the AASHTO test method (T104), is the total percentage loss of material (Overseas Road Note 19; 2002).

2.2.4 Cleanliness

Aggregate should be free of all silt and clay size particles. During HMA production, the ‘free’ silt and clay particles are removed by the dust extraction process (sucking out the dust) or are included as filler. (ERA Standard Technical Specification; 2002)

a. Decantation test

Initially the dry aggregate sample is disturbed to simulate the treatment it receives during transit at the asphalt plant. A deflocculating agent and ultrasonic vibration is then used to dislodge adherent fine particles before wet sieving using a 63µmsieve to determine their proportion.

b. Sand equivalent value

This test is utilized to establish the proportion of detrimental clay-like or plastic fines in fine aggregate passing the 4.75mm sieve. In the test, oven-dried fine aggregate and a solution of calcium chloride, glycerin and formaldehyde are mixed and poured into a graduated cylinder. Agitation loosens the plastic fines from the coarser sand-like particles and, after further addition of solution; the plastic fines are forced in to suspension. At the end of a prescribed sedimentation period the heights of sand and clay are measured. The Sand Equivalent Value is the ratio of the height of the sand to clay, expressed as a percentage (Taylor and Frances Group; 2006).

c. Plasticity index (PI)

This is defined as a range of moisture content, expressed as a percentage of the mass of an oven dried aggregate sample passing a 425µm sieve, within which the material is in a plastic state. It is the numerical difference between the liquid and plastic limit of the material. (AASHTO T-89, 1997)

2.3 Bitumen for use in HMA

2.3.1 Ageing determination tests and procedures

The objective of the laboratory tests described under this portion is to ensure that bitumen to be used in HMA will give satisfactory performance in service. Tests are conducted to conform the required properties of bitumen when it is delivered and others specify the limits of acceptable changes in bitumen properties during the various stages of the HMA production process (Taylor and Frances Group; 2006).

a. Loss on heating test (AASHTO – T 49 and ASTM – D 6)

This test is suitable for ranking or grading bitumen according to their tendency to harden and indicates that a material has been contaminated with light oils. The ageing conditions in the test are similar to those in bulk storage but nothing like those during mixing. In the test, samples of binder are placed in moving air oven and maintained at 163^{o}C for a period of 5 hours, while the shelf rotates approximately 5-6 times per minute. The samples are approximately 55 mm in diameter and 35mm deep. The main purpose is to determine the loss in mass of oil in asphalt compounds when heated as discussed above the loss is exclusive of water (Taylor and Frances Group; 2006)

b. Thin Film Oven Test (TFOT) (AASHTO – T 179 and ASTM – D 1754)

Practical conditions are simulated somewhat well by this test in that, despite being heated in a similar manner with loss on heating test, the effect of heat and air are determined from changes occurring in a physical properties measured after and before the oven treatment. It is claimed that the amount of hardening that takes place in this test approximates that obtained in practice during storage and mixing. However, in the test, diffusion into the bitumen film is still limited and it is not possible to obtain homogeneous hardening (Christopher Blandesand Edward Kearnery; March 2004).

i. Rolling Thin Film Oven Test (RTFOT) (AASHTO – T 240 and ASTM – D 2872)

This test simulates the mixing process more closely. In this test cylindrical glass containers holding 35gms of bitumen are fixed on a vertically rotating shelf. During the test the bitumen flows continuously around the inner surface of the container in a relatively thin film with pre-heated air being blown periodically into the container. The normal test procedure uses a temperature of 163oC for a period of 75 minutes. In this manner a homogeneously aged binder is obtained which experience has shown is equivalent to the degree of hardening observed during the mixing and laying of HMA (Taylor and Frances Group; 2006).

ii. Bitumen durability test

This test is an extended version of the RTFOT and has been shown to simulate the in-service ageing of the bitumen in thin seals over a period of years. In the test, a small portion of bitumen, already hardened in the RTFOT, is deposited from solvent on the inner walls of the glass container used in the RTFOT to give an even film approximately 20 microns thick. These films are then exposed to the action of air in a RTFOT type oven modified to maintain a temperature of 100^{o}C over long periods. The viscosity of the binder is then tested periodically using a sliding plate viscometer to establish how long it takes until the bitumen reaches a ‘critical viscosity’ (Christopher Blandes and Edward Kearnery; March 2004).

2.3.2 Consistency determination tests

Bitumen is thermoplastic materials and characterized by their consistency or ability to flow at different temperatures. The viscosity of bitumen determines how the material will behave at a given temperature and over a temperature range. The basic unit of viscosity is the Pascal second (Pa.s) where 1Pa.s = 10 Poise. The absolute (or dynamic) viscosity of bitumen, measured in Pascal seconds, is the shear stress applied to a sample in Pascal’s divided by the shear rate per second. Viscosity can also be measured in units of m2/s, or more commonly mm1 centistokes). These units relate to kinematic viscosity, usually measured by capillary tube viscometers. Kinematic viscosity is related to absolute viscosity by the expression:

Kinematic viscosity = Absolute viscosity/Mass density (Christopher Blandesand Edward Kearnery; March 2004).

a. Penetration test (AASHTO – T 49 and ASTM – D 5)

This is an empirical test in which a prescribed needle, weighted to 100gms, is allowed to bear on the surface of the bitumen for 5 seconds. The bitumen is held at a temperature of 25oC in air and water bath consequently for not less than 45 min to 1:30 hours. The depth, in units of 0.1 mm that the needle penetrates is the penetration measurement. As the test temperature rises, the bitumen gets softer and the penetration value is higher. This test is applicable for material having penetration grade less than 350 (Taylor and Frances Group; 2006).

b. Softening point test (AASHTO – T 53 and ASTM – D 6)

For this test, two samples of bitumen are confined in brass rings, loaded with steel balls, and suspended 25mm above a metal plate in a beaker of water or glycerol. The liquid is then heated at a prescribed rate. As the bitumen softens, the balls and the bitumen gradually sink towards the plate. At the moment the bitumen touches the plate the temperature of the water is determined, and this is designated as the ring and ball softening point (Christopher Blandesand Edward Kearnery; March 2004).

c. Bitumen viscosity

As the relationship between penetration and viscosity is often different for bitumen refined from different crude sources, a number of authorities have adopted bitumen specifications based on viscosity as well as penetration. Viscosity specifications are normally based on a viscosity range measured at60oC and a minimum value at 135oC. A temperature of 60oC was chosen as it approximates to the maximum temperature of in-service asphalt surfacing and 135oC because it approximates to the temperature at mixing and lay down (Taylor and Frances Group; 2006).

Another fundamental method of measuring viscosity is the sliding plate viscometer. This apparatus applies a shear stress (Pa) to a film of bitumen sandwiched between two plates and measures the resulting rate of strain (seconds). The viscosity in Pascal seconds (Pa.s) is given by shear stress divided by rate of strain. Depending on the load and the size of the sample, viscosities in the range of 105to 109Pa.s can be measured. A special feature of the apparatus is that the shear stress is the same throughout the sample and therefore it can be used to investigate the phenomena of shear stress dependence. Because only small amounts of sample are needed for the test, the sliding plate viscometer has been used extensively for research purposes; however, it is not normally used as a means of specifying penetration grade bitumen for construction purposes (Overseas Road Note 19; 2002).

d. Ductility

A number of specifications call for the ductility of the bitumen to be measured. The presence or absence of ductility is usually considered more significant than the actual degree of ductility. Some bitumen having an exceedingly high degree of ductility are also more temperature-susceptible. Ductility of bitumen is measured by an 'extension' type of test using a standard size briquette of bitumen molded under standard conditions and dimensions. It is then brought to a constant temperature, normally 25^{o}C. One part of the block is pulled away from the other at a specified rate, normally 5 cm per minute, until the thread of bitumen connecting the two parts of the sample breaks. The elongation (cm s) at which the thread breaks is designated the ductility of the bitumen (Overseas Road Note 19; 2002).

2.4 Mixture parameter

In determining the design asphalt content for a particular blend or gradation of aggregate by the Marshall method, a series of test specimens is prepared for a range of different asphalt contents so that the test data curves show well defined relationship (MS-2, 1997)

Mix components are blended in proportion by mass and expressed as percentages of the complete mix. However, the controlling factor in the design of mixes for all traffic level is the volume of each mix component. The basic definitions used in volumetric design are Air Void (VIM), Void in the mineral aggregate (VMA), Void filled with Bitumen (VFB) (Overseas Road Note 19; 2002).

Chapter 3

Research Methodology

3.1 Introduction

The Marshall Mix design method is the only method of Hot Mix Design of asphalt concrete preparation method which is frequently used in Ethiopia. Since the method is introduced to our country most steps are implemented according to the manuals instruction and recommendation without slight modification or research indication to modify some steps as per the country or topographic locations. Therefore, it's necessary to conduct research on the steps and some recommendation of Mr. Bruce Marshall and modify some of steps according to the country condition. The research methodology of this thesis includes the tests described under the literature review and the effects various consideration like compaction temperature, effects of remolding and reheating the sample for lab tests which are mostly deals with the operational conditions. Some of the conditions that this thesis focused on shall be discussed shortly as follows.

- It's obvious the viscosity of asphalt bitumen is depends on the heating temperature of the asphalt accordingly the site conditions due to different reasons the temperature of the mixture might be cooled or drops. Mostly the asphalt plant might be installed nearest to the aggregate crusher plant and during hauling or transportation of hot mix from plant to site, there might be some weather variations and the mix might be subjected to cooling before paving and compaction, this temperature drop will cause the bitumen to be less viscose and the compaction might not be achieved. This compaction temperature is not clearly specified on most standard specifications therefore, it's necessary to determine the compaction temperature by conducting some trial testes by collecting samples from site and compacting at laboratory at a different temperature.

- In most of manuals and technical specifications re-heating and re-molding of HMA is not allowed. But it is impossible to kip the sample of HMA temperature coming from site as it is and compact and conduct tests without reheating and remolding. This drop of temperature is due to two reasons this are; due to the transportation of HMA from paver or plant to laboratory their might be some drop of temperature and the sample is forced to reheated to the compaction temperature for quartering and running the lab test, the other reason is due to dispute of the contractors and consultants to conduct preliminary compliance tests. Therefore, I shall be checking the effect of re-heating and re-molding of HMA on laboratory tests and how it may or may not affect the result.

- The most common aggregate In Ethiopia used for HMA pavement road is crushed basaltic rock, and as we known that it is very difficult to get the finest particles or fillers passing sieve number 200 from such type of rock to the design specification. Therefore, the contractor is forced to produce fillers separately by installing dust crusher or forced to bring and use different type of fillers which is very coasty and economical to the project. Otherwise, there might be some quality compromising and manipulations of laboratory data. Accordingly during my research preparation I brought additional filler which is produced from the same crusher and expecting that this filler will be added due construction.

- The effect of water on compressive strength of compacted bituminous mixture shall be conducted by immersing with water under prescribed condition and performing the compressive strength test and studying the rutting effect of HMA. But due to the equipment shortage I couldn’t perform this test and I recommend this test should be done for further recommendation.

However, there are so many norms and trends are followed to prepare HMA in the laboratory and mostly some of norms and trends followed are not according to the recommended test procedure. Those followed norms and trends shall be the main targets of this thesis. Unless we compare the effects of the norms we follow with the normal procedure, we doesn’t know where is the exact problem or failure of our pavement road.

As it has been discussed in the chapter one, this norm and trends are came from knowledge gaps due to undeveloped curriculums concerning the hot mix design pavement roads even in the Civil Engineering courses of our universities. Whereas, this will end up with quality assuring problems and luck of confidential on the modifications and implementations of the standard quality specifications.

3.2 Basic procedure of preparing Marshall design method

Marshall Method is suitable for the design and field control of HMA mixtures containing different aggregates sizes. Aggregates are prepared and blended to give samples which conform to a selected particle size distribution. Initial mix design samples are prepared that cover a range of bitumen contents and are then subjected to a level of compaction. The properties of the compacted samples are then determined. These properties include; bulk density, air voids, and stability and deformation characteristics under load. If the mix properties do not meet specified mix design criteria, the mix must be reformulated and the tests repeated until an acceptable design is established.

3.2.1 Materials

For the initial mix design it is advisable to obtain sufficient quantities of coarse aggregate, fine aggregate, filler and bitumen to allow tests to be repeated if necessary or to test different aggregate grading. For each Mix design a total of 25kg of aggregate and 5 liters of bitumen are needed to make three sample specimen for each bitumen content and to allow for some wastage. The materials must be representative of those to be used on the project.

For HMA taken from an asphalt plant it is important to complete the Marshall compaction before the samples have cooled below the recommended compaction temperature. Insulated containers of large enough volume should be used for transporting the material to satisfy this requirement.

3.2.1.1 Aggregates

Bulk samples taken from each source of nominal size aggregate are reduced in the laboratory by quartering to give enough material to complete the mix design program. If additional filler is to be added during production then sufficient material should be obtained from the relevant source for use in the mix design process.

Representative Samples of each aggregate source and filler are subjected to wet sieve analysis and specific gravity tests. It is important that the sieve sizes used for the sieve analysis of the aggregates are the same as those specified in the final mix gradation.

a. Design of aggregate grading

Using the results of the sieve analysis obtained for each source of aggregate, a blend is computed which conforms to the specified aggregate particle size distribution. This can be most easily achieved using a excel computer spreadsheet or by graphical methods. It may be found necessary to change one or more of the aggregate sources to meet the specified particle size distribution.

The selection of aggregate sources may also be constrained by the number of cold feed bins that are available at the plant. It is preferable to obtain additional cold feed bins rather than pre-mixing two sources of aggregate before placing into a cold feed bin.

b. Batching of the Aggregate in Mixing tower(after drying dram)

The job mix formula prepared during laboratory mix design shall be interpreted to the asphalt plant operational capacity, so that the mix shall be batched accordingly in the mixing tower balance after the drying dram and sacked out mineral filler dusts. Each aggregate batch has been weighed and mixed with hot bituminous spreader in the mixing dram.

c. Checking After Mixing by Extraction of Bitumen

Every batch mixed in the mixing dram shall be cross checked by extracting the mixed aggregate by mechanical extraction machine and the sieve analysis test shall be performed to indicate the material distribution in the mix. This cross checking is also used to study the behavior of the asphalt plant balances or the dram itself.

It is obvious that the sample taken from the hot mix shall be compacted in the laboratory and under go all the laboratory tests and cross checked with prepared mix design.

3.2.1.2 Bitumen

A bulk sample of bitumen should be taken from either the storage tank or the delivery tanker. Bitumen samples should not be kept at the mixing temperature for longer than an hour during any test procedure. It is advisable, therefore, that the bulk sample of bitumen is divided into half-liter containers by pouring at as low a temperature as possible. In this way smaller volumes of bitumen can be heated when required. Containers of cold bitumen should not be heated over naked flames. Heating in an oven or on a sand tray is recommended.

Determination of mixing and compaction temperatures

The following properties of the bitumen are measured:

- ✓ Penetration at 25°C.
- ✓ Softening point (temperature at which penetration is assumed to be 800).
- ✓ Viscosity at approximately 105° to 115°C, 135°C and 160°C.
- ✓ Specific gravity.

The results of tests I) to III) are plotted on a bitumen test data chart. The plot will indicate the temperature viscosity characteristics of the bitumen and enable selection of the ranges of ideal mixing and compaction temperatures. The specific gravity of bitumen is required for the volumetric design of the mix.

3.2.2 Preparation of test samples

3.2.2.1 Mass of aggregate required

The amount of aggregate required for each sample is that which will be sufficient to make compacted specimens 63.5 ± 1.27mm high. This is normally approximately 1.2kg and should be confirmed by compacting a trial sample of 1.2kg of blended aggregate mixed at the estimated optimum bitumen content. If the height of the trial specimen falls outside the specified limits then the weight of aggregate used should be adjusted.

Having determined the weight of aggregate required, a minimum of 21 samples of aggregate complying with the design particle size distribution are placed in metal containers. Fifteen samples are heated to a temperature not exceeding 28°C above the mixing temperature.

3.2.2.2 Design bitumen content

The design bitumen content for the selected blend of aggregates is determined by testing specimens prepared at bitumen contents which span the expected design value. The expected design value is estimated from the following formula (Asphalt Institute, 1994) [2]:

$$DBG = 0.035a + 0.04b + Kc + F$$

Where,

- DBC = approximate design bitumen content, per cent by total weight of mix
- a = per cent of mineral aggregate retained on the 2.36mm sieve
- b = per cent of mineral aggregate passing the 2.36mm sieve and retained on the 0.075mm sieve
- c = per cent of mineral aggregate passing the 0.075mm sieve
- K=0.15for11-15%passingthe0.075mmsieve;

- 0.18for6-10%passing the0.075mmsieve;
- 0.20for5%orlesspassingthe 0.075mm sieve;

- F = 0-2% Based on absorption of bitumen. In the absence of other data, a value of 0.7 is suggested.

The aggregate samples are used to make triplicate specimens at the estimated optimum bitumen content and at two increments of 0.5 per cent above and below this optimum. If the estimated bitumen content proves to be different to the actual value then it may be necessary to use the spare aggregate samples to make specimens at one or two additional bitumen contents.

3.2.3 Mixing

Before mixing, the half-liter containers of bituminous are heated in an oven to the ideal mixing temperature as determined above. Mixing should be done in a mechanical mixer with a bowl capacity of approximately 4liters. The mixing bowl, mechanical stirrers and any other implements to be used in the mixing procedure must be pre-heated to the mixing temperature. The heated aggregate sample is placed in the mixing bowl and thoroughly mixed using a trowel or similar tool. A crater is formed in the center of the mixed aggregate into which the required weight of bitumen is poured. Mixing with the mechanical mixer will then produce a mixture with a uniform distribution of bitumen.

3.2.4 Compaction

The pre-heated mold, base plate, filling collar and an inserted paper disc should be Pre-assembled so that the sample can be compacted immediately after mixing is completed.

The mold is filled with the mixed material and the contents spaded vigorously with a heated spatula or trowel, 15 times around the perimeter and 10 times over the interior. The surface of the material is then smoothed to a slightly rounded shape onto which another paper disc is placed.

The temperature of the mix prior to compaction must be within the determined limits. The mold, base plate and filling collar are transferred to the Marshall Compaction apparatus and the sample compacted by the specified number of blows of the Marshall hammer.

After compaction, the mold assembly is removed and dismantled so that the mold can be inverted. The equipment is reassembled and the same numbers of blows are applied to the inverted sample. The mold assembly is then placed on a bench where the base plate, filling collar and paper discs are removed.

The mold and the specimen are allowed to cool in air to a temperature at which there will be no deformation of the specimen during extraction from the mold using an extrusion jack. The compacted sample specimen is marked for identification (symbolized) and allowed to cool to room temperature ready for testing. The whole procedure is then repeated on the remaining prepared samples.

3.2.5 Testing of specimens

The sample specimen blocks are then tested to determine their volumetric composition and strength characteristics.

3.2.5.1 Bulk specific gravity determination

The bulk specific gravity is determined for each specimen block at 25°C in accordance with the test procedure described in ASTM D2726. Stability and flow testing

After measuring the bulk specific gravity the specimen blocks are immersed in a water bath at 60°C ± 1°C for 35 ± 5 minutes. Each specimen block is then removed in turn and tested on a Marshall crushing apparatus to determine the stability and flow values. The mean value of stability and flow for each triplicate set of specimen blocks is calculated and recorded.

3.2.5.2 Determination of Void in Mix (VIM)

The maximum specific gravity of the mixes at very bitumen content must be determined to enable VIM to be calculated. After completion of stability and flow tests, two of each triplicate set of specimen blocks are dried to constant weight in an oven at 105 ± 5°C. Each pair of specimen is combined to give bulk samples to be tested in accordance with the ASTM D2041 procedure for the determination of maximum specific gravity of the mixes.

The test results are plotted and smooth 'best fit' curves drawn. The graphs plotted are: -

I. VIM vs Bitumen content.
II. VFB vs Bitumen content.
III. VMA vs Bitumen content.
IV. Stability vs Bitumen content.
V. Flow vs Bitumen content.
VI. BSG of mix vs Bitumen content.

3.2.5.3 Confirmation of design bitumen content

The design bitumen content is obtained from the relationship between VIM and bitumen content determined in the Marshall test. The VIM requirement is paramount after which it is necessary to ensure that all of the remaining specified mix criteria are also met.

If any of the criteria are not met or if it is considered that a more economical mix can be designed, then the whole design procedure will have to be repeated using an alternative blend of aggregates, particle size distribution or both.

3.3 Volumetric analysis

3.3.1 Specific gravity of volumetric analysis.

Because it is the volume of the individual components that is important for satisfactory mix design, the Bulk Specific Gravity (BSG) of each type of material must be measured so that volumes can be computed from the weights when necessary. The terminology and test methods used for volumetric analysis are shown in Table below.

Coarse aggregates may have been obtained from more than one quarry and the SG of individual sizes from a common aggregate source may be different.

Determination of the BSGs of the aggregates is based on the oven dried weight. Accuracy of measurements are important and it is recommended that they are determined to three decimal places. If the BSGs of the different aggregate sizes do not differ by more than 0.2 then the inaccuracies produced by proportioning by weight rather than by volume will be small.

The BSGs of the individual coarse aggregate fractions, the fine aggregate and mineral filler fractions are used to calculate the Bulk Specific Gravity (Gsb) of the total aggregate using the following formula:

$$G_{sb} = \frac{P_1 + P_2 + P_3 + \cdots P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3} + \cdots \frac{P_n}{G_n}}$$

Where,

- G_{sb} = bulk specific gravity for the total aggregate.
- P_1, P_2... P_n = individual percentages by
- G_1, G_2... G_n = individual bulk specific

During production of HMA it is essential that the plant produces the same aggregate blend that is adopted for the laboratory design mix. To complete the volumetric analysis of a bituminous mix, it is necessary to determine the maximum specific gravity (Gmm) of the loose HMA, the BSG of the compacted material (Gmb) and the specific gravity of the bitumen (Gb) used in the mix. Since the laboratory design is based on the volume of the constituents whilst plant operations are based on proportioning by mass, it is important to ensure that any changes to the plant mix comply with volumetric design requirements.

Volumetric terminology and test methods

Volumetric description	Terminology	Determined by test method	
		ASTM	AASHTO
a. Constituents			
Bulk Specific Gravity of coarse aggregate	G_{ca}	C127	T85
Bulk Specific Gravity of fine aggregate	G_{fa}	C128	T84
Bulk Specific Gravity of mineral filler	G_f	D854	T100
Bulk Specific Gravity of total aggregate	G_{sb}	_	_
Bulk Specific Gravity of bitumen	G_b	D70	T228
b. Mixed material Gmb			
Bulk Specific Gravity of compacted material	G_{bm}	_	_
Saturated surface dry specimens		_	T166
Maximum Specific Gravity of loose material	G_{mm}	D2041	T209
Air voids VIM D3203 T269	VIM	D3203	T269
Effective bitumen content	P_{bc}	_	_
Voids in mineral aggregate	VMA	_	_
Voids filled with bitumen	VFB	_	_

Table 3.1 Terminologies of volumetric equations.

3.3.2 Effective specific gravity of aggregate (G_{se})

Based on the Gmm of a bituminous mixture, the effective SG of the aggregate Gse, includes all void spaces within the aggregate particles, except those that absorbed bitumen, and is determined using:

$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}}$$

Where,

- ✓ G_{se} = effective specific gravity of aggregate.
- ✓ G_{mm} = maximum specific gravity of mixed material (no air voids).
- ✓ P_b = bitumen content (percent by total weight of mixture) at which ASTM D2041 test (G_{mm}) was performed.
- ✓ G_b = specific gravity of bitumen.

3.3.3 Maximum specific gravity of mixtures (G_{mm})

The determination of G_{mm} is of top importance to volumetric analysis, it is recommended that the determination should be carried out in duplicate or triplicate.

The G_{mm} for a given mix must be known at each bitumen content to allow the VIM to be calculated. G_{mm} can be measured at each bitumen content and a plot of VMA against bitumen content should produce a smooth relationship. This will indicate if any test result is suspect and that it should be repeated. Asphalt Institute suggests an alternative procedure because the precision of the test is best when the mixture is close to the design bitumen content. By calculating the effective SG (G_{se}) for the measured G_{mm}, using the following equation

$$G_{mm} = \frac{100}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}}$$

Where,

- G_{mm} = maximum specific gravity of mixture (no air voids).
- P_s= aggregate content, percent by total weight of mixture.
- P_b= bitumen content, percent by total weight of mixture.
- G_{se} = effective specific gravity of aggregate.
- G_b= specific gravity of bitumen.

According to ASTM D – 2041 the maximum specific gravity of mixture is conducted by mixing separately so that the weight of mixture in air shall take (A), and the jar as per the test procedure indicates filled with water and the weight will be recorded as (B), the jar is filled with water and sample shall be free of air as per discussed in the test method and the weight taken as (C).

The theoretical maximum specific gravity shall be determined as follows:

$$G_{mm} = \frac{A}{A + B - C}$$

3.3.4 Bitumen absorption

Bitumen absorption is expressed as a percentage by weight of aggregate and is calculated using:

$$P_{ba} = \frac{100(G_{se} - G_{sb})}{G_{se}G_{sb}}$$

Where,

- P_{ba}= absorbed bitumen, percent by weight of aggregate.
- G_{se}= effective specific gravity of aggregate.
- G_{sb}= bulk specific gravity of total aggregate.
- G_b= specific gravity of bitumen.

3.3.5 Effective bitumen content of the mix

The effective bitumen content does not include absorbed bitumen. It is calculated using:

$$P_{be} = P_b - \frac{P_{ba}P_s}{100}$$

Where,

- P_{be}= effective bitumen content, percent by total weight of mix.
- P_b = bitumen content, percent by total weight of mix.
- P_{ba}= absorbed bitumen, percent by weight of aggregate.
- P_s= aggregate content, percent by total weight of mix.

3.3.6 Percent voids in mineral aggregate (VMA)

The Voids in Mineral Aggregate includes the volume of air between the coated aggregate particles and the volume of effective bitumen. It is expressed as percent by weight of total mix using:

$$VMA = 100 - \frac{G_{mb}P_s}{G_{sb}}$$

Where,

- VMA = voids in mineral aggregate.
- G_{mb} = bulk specific gravity of compacted mix.
- G_{sb}= bulk specific gravity of total aggregate.
- P_s= aggregate content, percent by total weight of mix.

3.3.7 Percent air voids in a compacted mix

The air voids, VIM, in a compacted mix is the volume of air between the coated aggregate particles. It is calculated using:

$$VIM = 100 * \left(\frac{G_{mm} - G_{mb}}{G_{mm}}\right)$$

Where,

- VIM = air voids in compacted mix, percent of total volume.
- G_{mm} = maximum specific gravity of mix.
- G_{mb}= bulk specific gravity of compacted mix.

3.3.8 Percent voids filled with bitumen (VFB) in a compacted mix

The voids filled with bitumen, VFB, is the percentage of VMA that is filled with bitumen. It is calculated using.

$$VFA = 100 * \left[\frac{VMA - VIM}{VMA}\right]$$

Where,

- VFB = voids filled with bitumen (percent of VMA).
- VMA = voids in mineral aggregate, percent of bulk volume.
- VIM = air voids in compacted mix, percent of total volume.

Marshall Mix design method

Marshall Mix design method is used to determine the proportioning and estimation of ingredients used in the mix. And also help to compare the characteristics of the mix and the mixture parameters prepared in the laboratory with the standards specification before starting the mixing process.

Marshall Mix design method is started by testing and studying the individual parameters of the ingredients to be used in the mix separately.

After studying the parameters of the ingredients, the job mix formula shall be calculated by sieve analysis method. That means the weight of all aggregates on individual sieve shall be measured and converted to percentile. Based on the specification given the by trial and error all the bins are batched by using estimated design bitumen content.

Every trial mix has three batches, and every trial mix has been conducted by different bitumen content varying by 0.3%. Mix design shall be prepared for 5 trial mix designs varying by 0.3% and used for comparing and analyzing the effects in the mix and the three per’s shall be used for taking average. The aggregate ingredients and bitumen are mixed at mixing temperature and compacted at compaction temperature that means the compaction temperature is 130^{o}C and mixed at 146^{o}C. An aggregate weighing about 1200gm and the 60/70 grade asphalt were heated to a temperature of 175^{o}C and 130^{o}C, respectively. Then, these ingredients were mixed at a temperature of 146^{o}C, as determined before. The percent by weight of asphalt content for all mixes was taken with respect to the total weight of the mixture (batch). The batch was then placed in the preheated mold and compacted at 130^{o}C using a 75 blows on both sides of the specimen. After compaction, the specimen were allowed to cool and removed from the mold by means of an extrusion jack. In accordance with the Marshal procedure, each compacted test specimens were subjected to determination of unit weight, void analysis, stability, flow tests. Then, plots were made for the determined values of each respective specimen prepared using different types of mineral fillers as indicated in Appendix A.

The procedure used for determining of optimum asphalt content for a particular mixture under evaluation was adopted from the publication by the Asphalt Institute [2], where both the American Society for Testing and Materials given by ASTM D1559 and American Association of State Highway and Transportation Officials given by AASHTO R-12 standardized it.

3.4 Re-heating and re-molding

In the hot mix asphalt (HMA) construction industry, volumetric parameter of asphalt has an important role on the acceptance criteria of standard specifications. This volumetric parameters are air void (Va), Void filled with asphalt (VFA) and void in mineral aggregate (VMA).

These volumetric parameters are an indicative laboratory tests and the laboratory samples are collected from different places like from asphalt plant or from paver. However, there might be some laboratory data difference in the compaction temperature in the volumetric parameter during re-heating of mixture samples that have cooled below laboratory compaction temperature and reheated to compaction temperature.

The laboratory experiment shall be conducted on four samples of mixture storage times (zero, five, 12 and 24 hours). The storage time means the time elapsed after mixing to compaction, while the compaction temperature is reduced due to aging. Therefore, zero time is referred to no time elapsed is aloud and temperature drop is not aloud, the sample of mixture shall be compacted immediately after mixing and all the volumetric parameters and performance tests shall be conducted. Five hour means the time elapsed for transportation of a sample from paver and/or the time between mixing to re-heating is five hour therefore, the mixture must be reheated to compaction temperature. The sample shall be quartered to a three per's of all laboratory test parameters. 12 hrs and 24 hrs are also the same meaning with five hours definition.

All samples are subjected to volumetric parameter testes and performance testes described as following table

Chapter 4

Test Result and Discussion

4.1 Introduction

The test results of 17 tests are evaluated in accordance of Marshall Mix design method on this chapter. These mixtures are prepared for different operational condition verifications. The temperature control to be implemented or adopted during paving has great role on assuring the mix quality; in addition compacting of the cooled mix or reheating to the compaction temperature might be other option for reducing the disputes between the construction parties.

Therefore, the tests conducted on reheating the cooled hot mix asphalt are evaluated by comparing with standard hot mix asphalt preparation. In the same manner in case of the temperature drop of the mixture, the compaction effort shall be evaluated by comparing the compacted specimen at different degree centigrade of compaction temperature. Those effects of temperature shall be compared and contrasted with the Marshall Mix design method and ERA manuals.

Even though, the main objective of this thesis is studying the effect of the temperature on hot mix asphalt; the Marshall Mix design properties and the mix design problems shall be studied and the results are evaluated on this chapter.

4.2 Material Test Result

The thesis includes all the tests described under the literature review including all ingredients of mix and mixture tests and tested as per the methodology discussed earlier. The effects various consideration like compaction temperature, effects of remolding and reheating the sample for lab tests, moisture susceptibility of the mix which are mostly deals with the operational conditions are briefly discussed under this part.

The effects that this research studies are compared with the trial mix design prepared previously and the ingredients that we use for the mix design shall be studied prior to the trial mix. Therefore, the material testing shall be discussed here under step by step.

4.2.1 Coarse and Fine aggregate

The aggregate used in the research were subjected to different quality testes in order to find out their physical characteristics and suitability of the materials in the pavement road construction. The aggregates were obtained from Ageremariam, Arab Contractor's crusher site and their laboratory is used for some of research testes. The grading requirement and obtained JMF of the aggregate used for the research is indicated in the table 4.1

Sieve Size (mm)	Combined Grading (% Pass)	Median of the Spec. (% Pass)	Tolerance limit as per ERA 2002		Spec limit (% pass)	
			Lower (% pass)	Upper(% pass)		
26.5	100.0	100.0	100	100	100	100
19.0	94.3	92.5	89	99	85	100
13.2	78.4	77.5	73	83	71	84
9.5	71.3	69.0	66	76	62	76
4.75	57.2	51.0	53	30	42	60
2.36	43.3	39.0	39	47	30	48
1.18	29.9	30.0	26	34	22	38
0.600	22.3	22.0	18	26	16	28
0.300	13.3	16.0	12	16	12	20
0.150	9.1	11.5	8	11	8	15
0.075	6.1	7.0	5	7	4	10

Table 4.1 Percent by pass of aggregate used for HMA design.

Sieve analysis test shall be conducted according to AASHTO T-27, by arranging the serious of sieve descending opening millimeters and the estimated amount of sample prepared shall be screened and let the particles pass through the openings and measure the samples of retained, calculate the present of passing and retaining on each sieve. However, the samples for HMA design shall be collected from the hot bin asphalt plant. Therefore, it is necessary to classify the hot bin batching groups. Accordingly, the hot bin batching for this mix shall be classified in to several groups and detail calculations proportions are attached in Appendix 1.

The hot bin groups are 12~17mm, 17~10mm, 10~5mm, 5~3mm, 3~0mm, stone Dust and Mineral fillers with the percentage of 16%, 13%, 14%, 8%, 42%, 4% and 3% respectively. Each hot bin group has to be analyzed for grading separately and combined with different percent proportioning to obtain in the specification envelope.

The specification named as upper and lower limit on the table above and below chart is taken from the ERA standard technical specification 2002 table 6400/8 continuously coarse graded and project specification.

The obtained specimen grading is also subjected to ERA tolerance given on the specification table 6400/15 that the combined aggregate and filler grading shall not deviate from the target grading it is called Job Mix Formula.

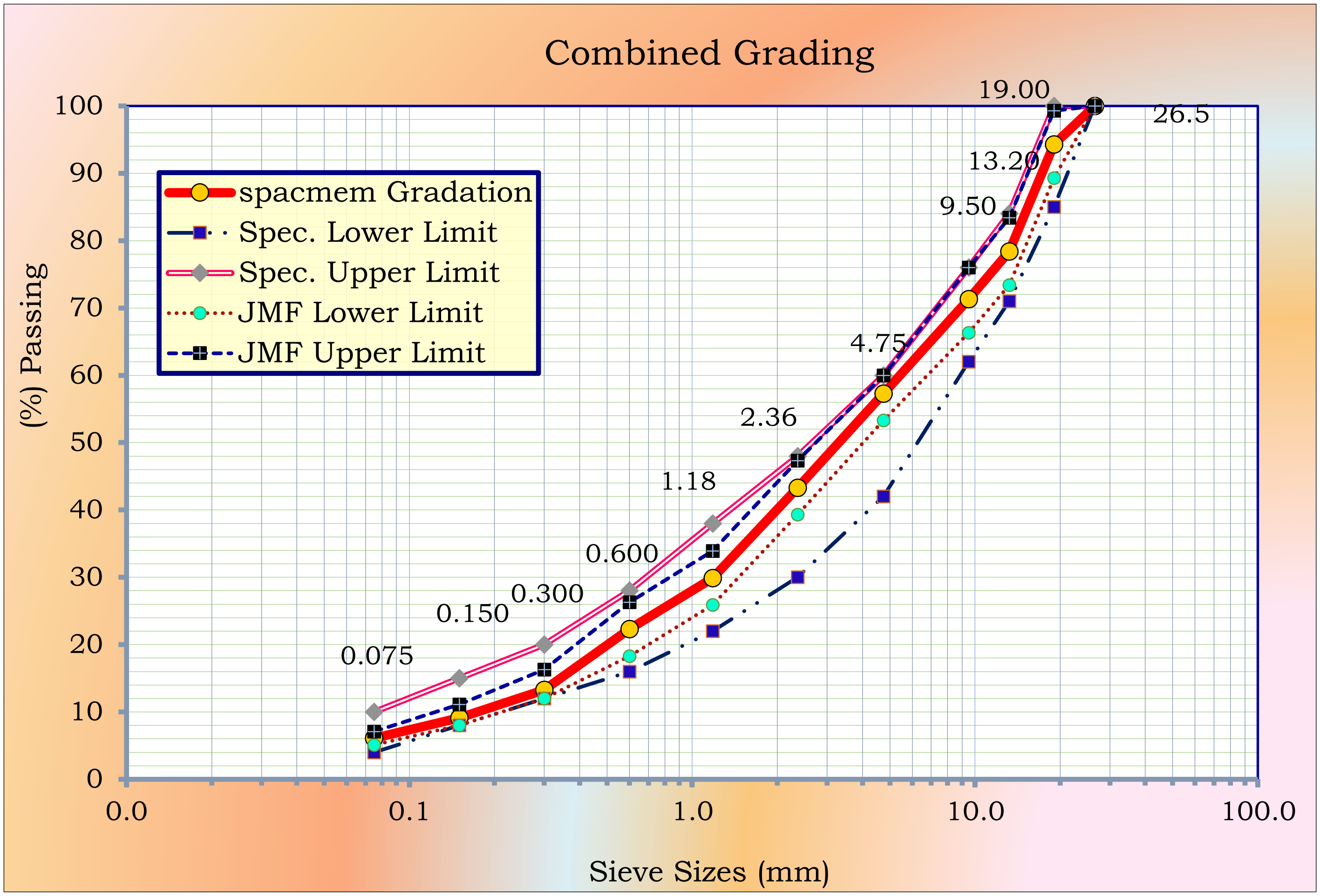

Figure 4.1 Combined Grading

The grading analysis for all hot bin aggregates shall be conducted separately and eight samples are quartered and prepared. Accordingly the sieve analysis for all hot bin aggregates are attached with the appendix A

Physical property of the crushed aggregate shall be conducted to investigate the suitability of the material before utilization of road construction, various tests were conducted and the results are indicated in table 4.2

No	Test description	Method	Result	Specification
1	LAA (%)	AASHTO T-96	16.3	< 30%

2	ACV (%)	BS 812, Part 110	15	Max 25%
3	TFV (%)	BS 812, Part 111	173	160KN
4	Flakiness index	BS 812, part 105	19%	Max 25%
5	Plastic index		NP	< 4 %
6	Water absorption	ASTM C-127	1.4	Max 2
7	Affinity of asphalt (coating and stripping)	AASHTO T-182	>95	>95
8	Sand Equivalent	AASHTO T-107	77	Min 50
9	Durability Sodium sulfate	AASHTO T-107	1.00	Max 12
10	Durability magnesium sulfate	AASHTO T-107	1.00	Max 18

Table 4.2 physical property of aggregate

4.2.2 Asphalt Binder

Asphalt binder used for this thesis is bituminous grade 60/70 penetration and it was subjected to different quality tests to determine their physical properties, where the test results are summarized here under.

No	Test description	Method	Result	Spec.
1	Penetration 0.1 unit (25^{o}C, 5sec 100gm)	AASHTO T-49	60	60 – 70
2	Flash pint (^{o}C)	AASHTO T-48	310	Min 230
3	Ductility, cm @ 25 ^{o}C	AASHTO T-51	>100	Min 100
4	Loss in heating % Wt	ASTM D -175	0.07	-
5	Softening point (^{o}C)	ASTM D-36	50.6	Min 6
6	Specific gravity	AASHTO T-228	1.0263	-
7	Solubility in Trichloroethylene	ASTM D – 2025	99.9	Min 99
8	Thin film oven Test	ASTM D – 175	-	-

Table 4.3 physical property of asphalt bitumen

4.2.3 Mixture tests

Mixture characterization tests are used to determine the performance characterization and volumetric parameters of the mixture. This are the specific gravities, air void, Void in mineral aggregate, void filled with asphalt, resistance to plastic flow of bitumen mixture and strength of the mixtures. HMA mixtures can be tested either by compacted specimen and loose mixtures. Any mixtures shall be properly designed as per marshal mix design method and can have the following parameters determined. The components listed below shall be determined by Marshall Mix Design method and measured by different standard testing methods.

As a reference to this study the mix design of hot mix asphalt is prepared by 60/70 bitumen grade as per the Marshall Mix Design method described above. The summary of 5 trial mix design varying by 0.3% of bitumen content shall be briefly discussed under Appendix A, but the trials that fulfill the Marshall design and project specification is tabulated here under:

This mix design is conducted to use as reference of this study that focuses on the effects of temperature on hot mix like compaction temperature from practical point of view and reheating and remolding effect of hot mix asphalt on laboratory evaluation.

MARSHALL MIX DISGIN FOR ASPHALT CONCRETE WEARING COURSE (MARSHALL METHOD : AASHTO T-245)

Aggregate Bin Source	Hot Bin	Aggregate Source :	Quarry site at Ageremariam offset 8Km to Shakiso
Trial Mix No.	6	Date of Testing	8/2/2016
Remark	TRIAL MIX DESIGN	Lab Ref.No.	20

% Asphalt		4.40 %			4.70 %			5.00 %			5.30 %			5.60 %		
Specimen Number		1.1	1.2	1.3	1.1	1.2	1.3	1.1	1.2	1.3	1.1	1.2	1.3	1.1	1.2	1.3
SPECIFIC GRAVITY																
A-wt. Of specimen in Air(dry)		1253.2	1256.3	1256.0	1262.8	1256.7	1259.7	1262.7	1261.9	1259.6	1262.5	1259.4	1272.6	1262.9	1262.0	1262.5
B-wt. Of specimen in Air(SSD)		1255.6	1259.0	1259.0	1264.7	1258.4	1261.4	1263.7	1263.2	1260.7	1262.9	1259.9	1273.3	1263.7	1262.9	1263.3
C-wt. Of spcimen in water		751.8	756.7	755.9	762.9	761.2	761.6	763.7	764.6	763.1	767.8	765.4	773.1	767.3	768.9	768.5
V-Volume of specimen	V=B-C	503.8	502.3	503.1	501.8	497.2	499.8	500.0	498.6	497.6	495.1	494.5	500.2	496.4	494.0	494.8
G_{mb}-Bulk Specific Gravity @25°c	G_{mb}=A/V	2.487	2.501	2.497	2.517	2.528	2.520	2.525	2.531	2.531	2.550	2.547	2.544	2.544	2.555	2.552
Conversion Factor (k)	25 °C	1.00000	1.00000	1.00000	1.0000	1.0000	1.0000	1.00000	1.00000	1.00000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
G_{mb}-Bulk Specific Gravity @25°c	G_{mb}=G_{mb}xk	2.487	2.501	2.497	2.517	2.528	2.520	2.525	2.531	2.531	2.550	2.547	2.544	2.544	2.555	2.552
G_{mb}- Avg.Bulk Sp. Gravity @25°c			**2.495**			**2.522**			**2.529**			**2.547**			**2.550**	
G_{mm}-Max. Theoretical Sp. Grav			**2.679**			**2.665**			**2.647**			**2.643**			**2.626**	
Voids																
Effective bitumen content (%)	$P_{be}=P_b-(P_{ba}*P_s)/100$		3.59			3.89			4.19			4.50			4.80	
V_a- % air voids	$V_a=100x(G_{mm}-G_{mb})/G_{mm}$	7.17	6.64	6.79	5.55	5.14	5.440	4.61	4.38	4.38	3.52	3.63	3.75	3.12	2.70	2.82
Average V_a-%Air void	**Spec. (3-5 %)**		**6.87**			**5.38**			**4.46**			**3.63**			**2.88**	
V_{ma}-% void in Mineral Agg.	$V_{ma}=100-(G_{mb} \cdot P_s/G_{sb})$	15.8	15.4	15.5	15.1	14.7	15.0	15.1	14.9	14.9	14.5	14.6	14.7	15.0	14.6	14.7
Average V_{ma} (%)	**Spec. (> 14 %)**		**15.6**			**14.9**			**15.0**			**14.6**			**14.8**	
V_{fa}-% void Filled with Asphalt	$V_{fa}=(V_{ma}-V_a)/V_{ma}$ x 100	54.6	56.9	56.2	63.2	65.0	63.7	69.5	70.6	70.6	75.7	75.1	74.5	79.2	81.5	80.8
Average V_{fa} (%)	**Spec. (65 - 75 %)**		**55.9**			**64.0**			**70.2**			**75.1**			**80.5**	
FLOW & STABILITY																
Height of the specimen -H	cm	63.13	62.54	62.85	62.70	62.12	62.11	62.28	62.13	61.64	61.66	61.45	62.22	62.01	61.55	61.86
Maximum Load	KN	8.79	9.03	9.07	9.1	9.48	8.78	9.87	11.2	10.88	10.96	12.47	10.97	10.22	11.16	8.42
Corrected Load (From Callibration Cert.)	e	11.36	11.67	11.73	11.77	12.26	11.35	12.76	14.48	14.07	14.17	16.12	14.18	13.21	14.43	10.89
Stability conversion factor	f	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.09	1.09	1.04	1.04	1.09	1.09
Corrected Stability	KN	11.81	12.14	12.20	12.24	12.75	11.80	13.27	15.06	14.63	15.45	17.57	14.75	13.74	15.73	11.87
Average Stability	KN **Spec. (Min. 9 KN)**		**12.05**			**12.26**			**14.32**			**15.92**			**13.78**	
Flow	mm	2.48	2.71	3.83	3.03	3.55	2.91	2.68	3.68	2.83	3.32	2.97	3.52	2.90	3.63	2.92
Average Flow	mm **Spec.(2-4 mm)**		**3.01**			**3.16**			**3.06**			**3.27**			**3.15**	
Ratio																
Filler/Binder	**Spec.(0.6-1.2mm)**		0.68			0.64			0.60			0.57			0.54	

Table 4.4 Marshall mix Design for Asphalt Concrete wearing course

No	Description of test	Average Test Result of Mix design				
		4.4% bitumen content	4.7% bitumen content	5.0% bitumen content	5.3% bitumen content	5.6% bitumen content
1	Bulk Specific gravity	2.495	2.522	2.529	2.547	2.550
2	Theoretical specific gravity (Gmm)	2.679	2.665	2.647	2.643	2.626
3	Air void (Va)	6.87	5.38	4.46	3.63	2.85
4	Void filled with asphalt (VFA)	55.9	64.0	70.2	75.1	80.5
5	Void in mineral aggregate (VMA)	15.6	14.9	15.0	14.6	14.8
6	Stability	12.05	12.26	14.32	15.92	13.78
7	Flow	3.01	3.16	3.06	3.27	3.15

Table 4.5. The summary of Mix Design

4.2.4 Re-heating and re-molding

The test result of reheated and remolded Hot Mix asphalt compacted after reheating at four different temperatures are subjected to volumetric parameter testes and performance testes described as following table

No	Description of test	Test Result after reheating and remolding of hot mix			
		Zero time	Five hour	12hrs	24hrs
1	Bulk Specific gravity	2.534	2.531	2.529	2.537
2	Theoretical specific gravity (Gmm)	2.647	2.647	2.647	2.647
3	Air void (Va)	4.28	4.39	4.46	4.14
4	Void filled with asphalt (VFA)	71.4	71.0	70.6	72.1
5	Void in mineral aggregate (VMA)	15.0	15.1	15.2	14.9
6	Stability	13.96	14.32	14.01	14.00
7	Flow	3.17	3.20	3.13	3.10

Table 4.6 effect of reheating and remolding

4.2.5 Effect of compaction temperature

The viscosity of bitumen asphalt is depends on the heating temperature. If the mixture has high viscosity, the workability of the mixture also increased. The compaction temperature is recommended to be nearest to the mixing temperature but if the temperature drops due to some reasons the performance of the pavement asphalt might be reduced. The experiment on the compaction temperature has been done by delivering the samples to lab and compacting with a different temperature. Two pers of samples are prepared and compacted at 60, 70, 80, 90, 100, 110, 120, 130, 140, 150 and 160^{o}c temperature and the results are summarized as follows

Test Description	**Compaction temperature at a different ^{o}C**										
	60	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**
Bulk Specific gravity	2.510	2.512	2.515	2.524	2.534	2.536	2.539	2.540	2.540	2.541	2.543
VIA	5.18	5.10	5.01	4.67	4.27	4.20	4.10	4.04	4.06	4.02	3.95
VMA	15.8	15.7	15.7	15.4	15.0	15.0	14.9	14.8	14.9	14.8	14.7
VFA	67.3	67.5	68.0	69.6	71.6	71.9	72.5	72.7	72.7	72.9	73.2
Stability	8.00	8.94	9.42	10.49	12.37	12.98	13.58	14.46	13.65	14.86	15.20
Flow	4.80	4.50	3.85	3.80	3.60	3.00	2.90	2.45	2.50	3.20	3.35

Table 4.7 compaction temperature

4.3 Test result Discussion

The test results of this thesis is deals with the comparison of the mix design performed as per the Marshall Mix Design method and the temperature effects of hot mix by conducting; this are reheating and remolding at a different hours and effect of compaction temperatures of hot mix on the Marshall parameters.

Therefore, the discussion will lead to the operational condition recommendations like the effects that will happen on the Marshall parameters if the sample is cooled down to less than compaction temperature and reheated and compacted at a compaction temperature. And the other recommendation is deals with the exact compaction temperature and what will happen if we compact at lesser temperature and higher temperature.

The mix design performed is conducted as per the Marshall Mix design II and used for only the target criteria used for comparisons.

4.4 HMA mix design

Different trial mixes are prepared to understand the Marshall Mix design method and to gate more acceptable proportion of the mix according to ERA standard technical specification.

From the above table the bulk specific gravity of the mix increased with bitumen binder content increase. This shows that the materials densification or specific gravity of the mix has direct relation binder content. The result also shows that the theoretical specific gravity has slight decrement while the binder content is on increment.

From volumetric parameters air void of the mix decreased when the binder content increases, this shows that the voids are filled with fillers coated by bitumen binder and if the bitumen binder content is lesser the mixture has an coated asphalt aggregate with full of voids. In the same manner also the voids filled with asphalt increased with the binder content increment. But, the voids in mineral aggregate slightly decreased up to 5.3% binder content and increased on 5.6% bitumen content. The stability shall be increased up to optimum binder content and started to decrease, this shows that the densification of the aggregate material property is depends on the amount of the binding agent added. i.e, until the optimum binder content is achieved the stability increases and when the binder content increased beyond the OBC the stability started to decrease. The charts showing all the above discussed pointes here under;

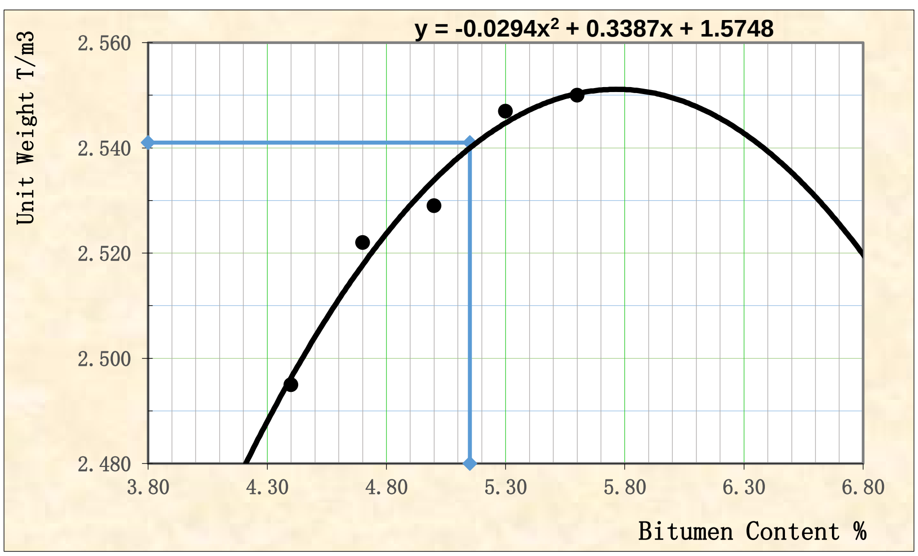

Figure 4.2 Bitumen content Vs Unit weight

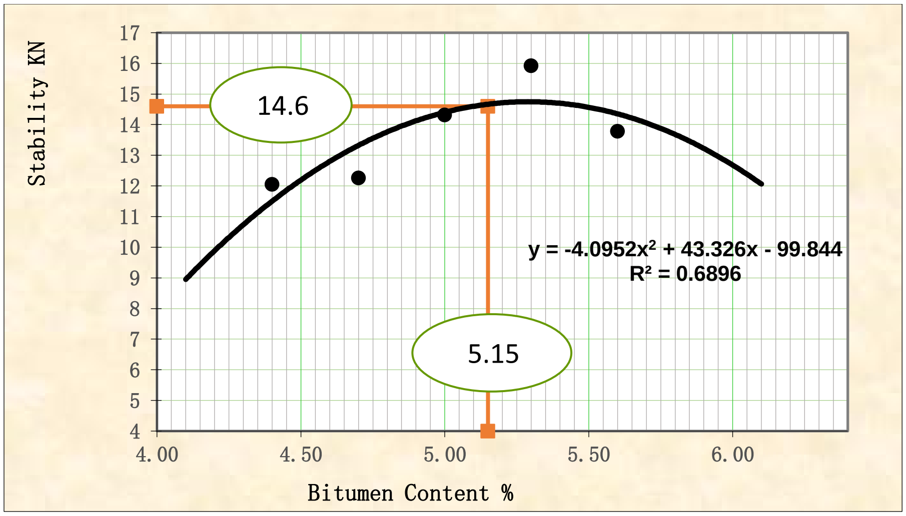

Figure 4.3; Binder content Vs stability

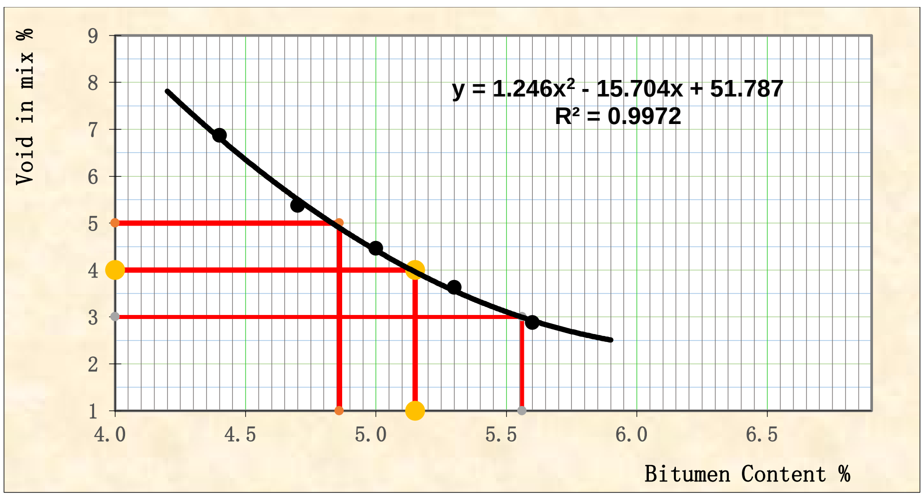

Figure 4.4; Void in mix Vs Binder content

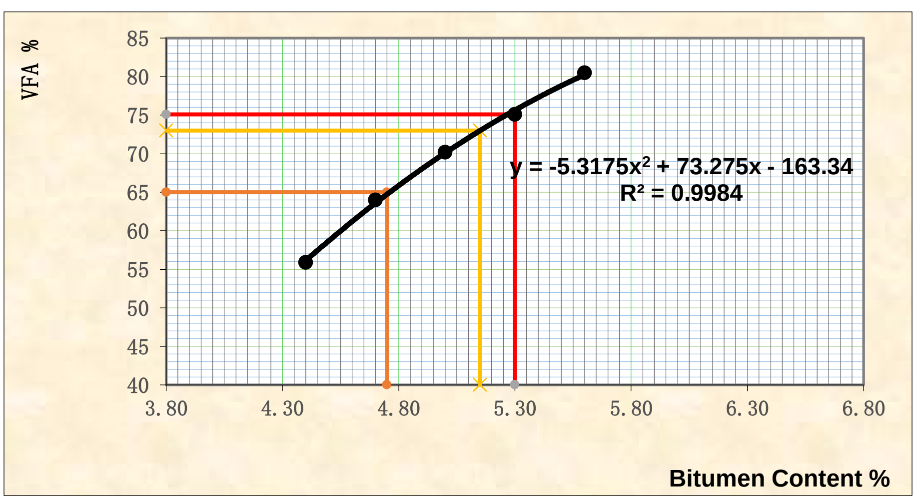

Figure 4.5; Bitumen Content Vs VFA

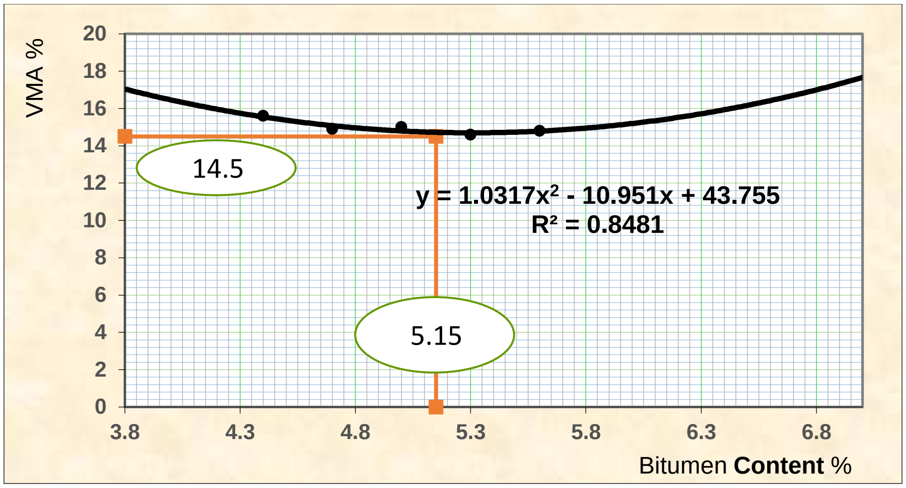

Figure 4.6; VMA Vs Bitumen Content

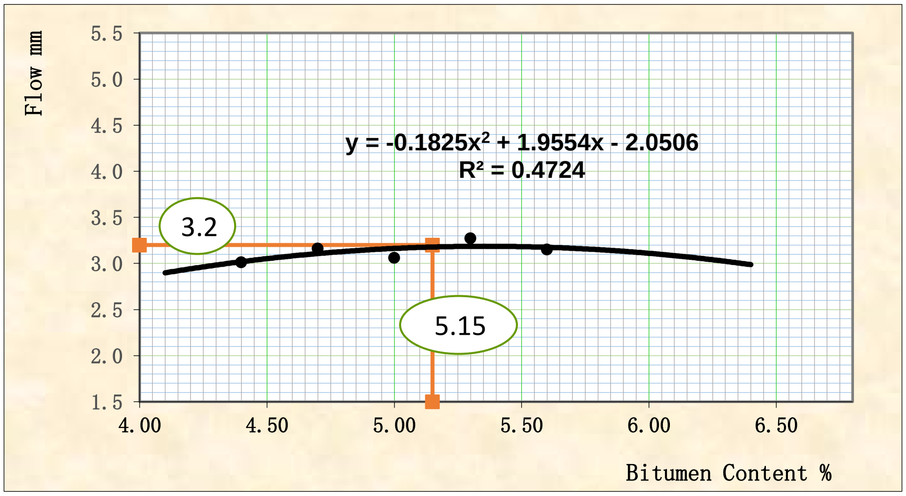

Figure 4.7. Flow Vs Binder Content

4.5 Effect of Temperature on HMA Compaction

The single most important factor that affects the long-term durability of a hot-mix asphalt (HMA) pavement is the density of the mix that is achieved by the contractor at the time of construction. The density of a material is defined as the weight of the material, which occupies a certain volume of space. The compaction process causes the asphalt-concrete mix to be compressed and its volume reduced. As the density of the HMA material increases, the air-void content of the mix decreases (they are inversely proportional to each other).

If the compacted mix has high air-void content, the mix will not perform as well under traffic. Similarly, if the compacted mix has low air-void content, the mix will be susceptible to permanent deformation or rutting and also to distortion under the applied traffic loads. Thus, for the mix to perform as expected, the contractor must be able to compact the mix to the desired level of density or air void content at the acceptable range of compaction temperature.

The viscosity of bitumen binder is fully depends on the heating temperature of the mix or the binder. Therefore, the high viscosity of the mix shall allow the aggregate materials to be reoriented and interlocked during placing and compaction. Asphalt-concrete mix must be fully compacted before it cools to a temperature of less than degree of compaction. At temperatures above this, the mix is normally still warm enough for the compaction equipment to reorient the aggregate particles into their densest configuration. Below that temperature, however, the mix is generally too stiff to increase in density any significant amount with continued rolling, although roller marks can often be removed below this compaction cutoff temperature. The mix must, therefore, be compacted while it is still hot.

Therefore, the determining compaction temperature shall play a great role on achieving the desired standard specifications and knowing the acceptable range of compaction temperature is also important during operational condition.

To propose the range of compaction temperature 11 per samples are prepared to compact at different temperature those samples are initiated from the previously prepared mix design on OBC range and tests are conducted after compaction and the summaries are discussed hereunder;

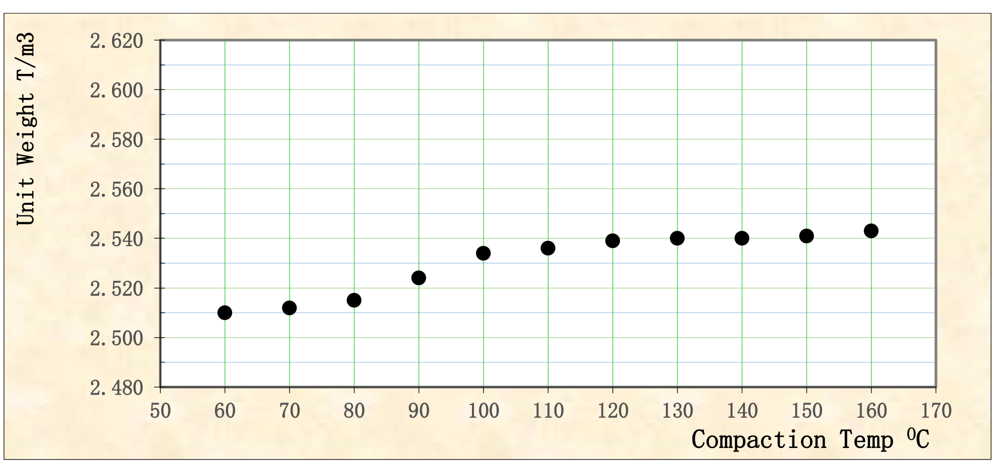

Figure 4.8; Unit weight of the compacted mix Vs compaction Temperature

From the above chart the unit weight of the compacted mix slightly increased from 60°C to 100°C of compaction temperature and the unit weight becomes similar after 100°C. This shows that the compaction temperature of 100°C has similar effect with the above temperature.

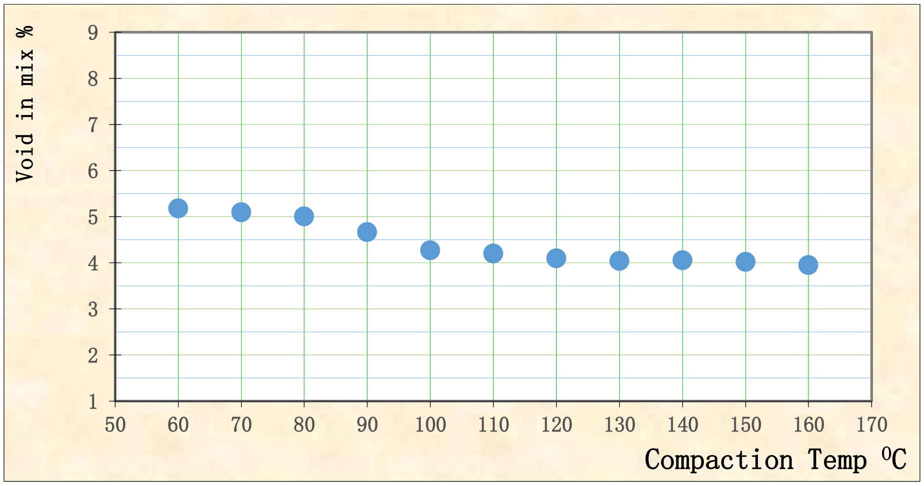

Figure 4.9; Void in mix Vs Compaction temperature

As we can see from above chart the void in the mix is decreasing while the compaction temperature increasing. The acceptable void in the mix is less than 5% and greater than 3%. Therefore, the acceptable compaction temperature shall be from 80°C to the end of considered temperature160°C.

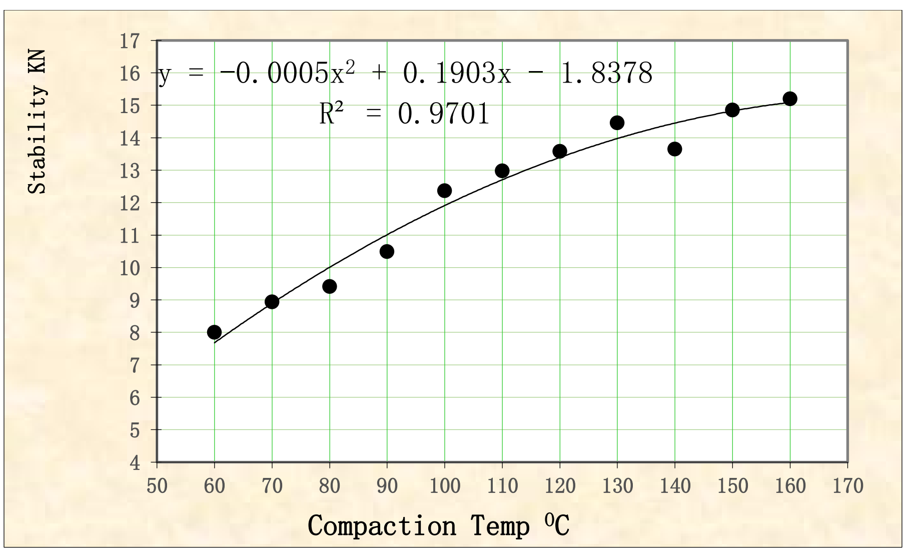

Figure 4.10; Stability Vs Compaction Temperature of HMA

As we can see from the above graph the stability of the compacted spacemen shall be increased as the temperature increased they have direct relation. Hence the heating temperature increased the spacemen density increase and voids are reduced then the stability or strength of the materials also increased. According to ERA manual the acceptable range of the spacemen stability shall be grater the 9Mpa and from above test result all above 80oC compaction temperature achieves the standard specification.

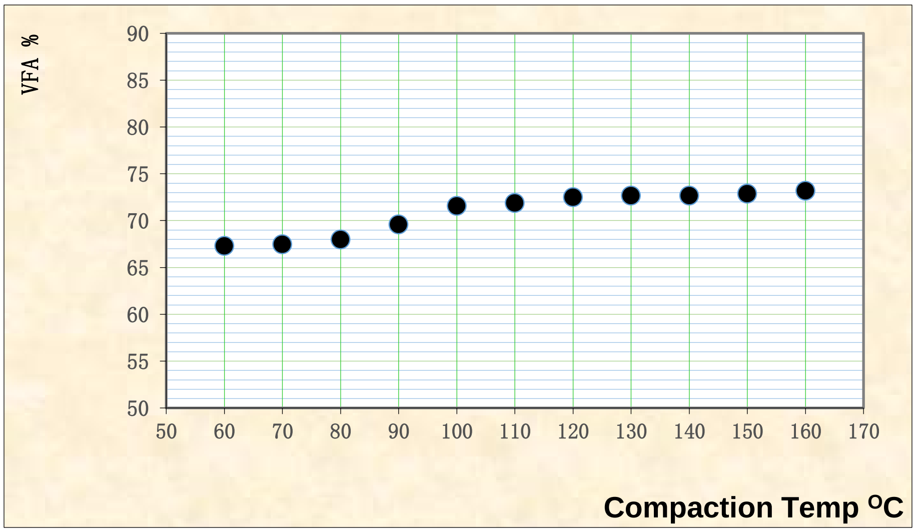

Figure 4.11. Void filled with asphalt Vs Compaction Temperature

According to the chart shown above the as the compaction temperature increased the Voids filled with asphalt increased but, the effects are slight change. In accordance to the Ethiopian Roads Authority manual the VFA value for HMA shall be accepted in between 65% to 75%. Therefore, the above all VFA values are accepted and all the trial compaction temperatures are has no effect on VFA value.

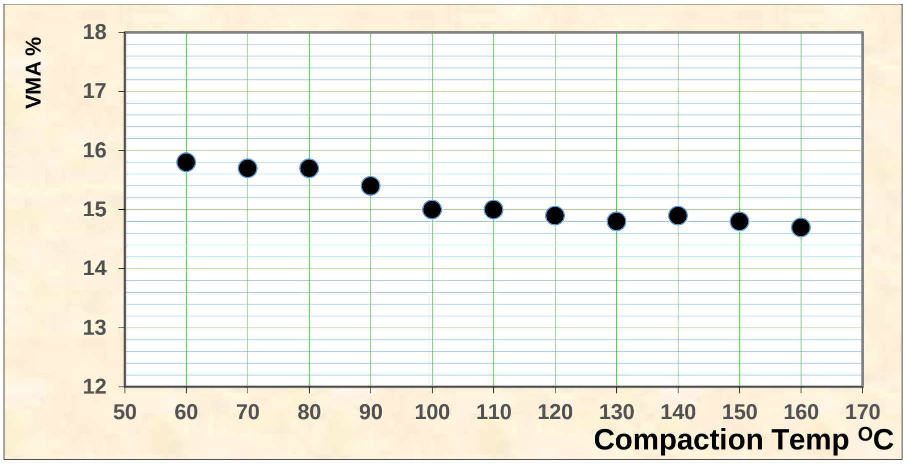

Figure 4.12; Void in mineral aggregate Vs Compaction temperature

From the above chart as the compaction temperature increased the Void in mineral aggregates decrease. It is clearly seen that when the compaction temperature becomes higher the aggregate particles shall be rearranged to higher density and the void in between aggregate particles or voids filled with asphalt shall be less.

4.6 Effect of Reheating and Remolding on HMA Sample

Reheating and Remolding of HMA used for laboratory test sampled from paving plant or mixing plant shall be allowed as a normal procedure after investigating the effect of reheating HMA if the mixture is cooled to lower than the compaction temperature. During quality investigation of HMA sample taken from site to central laboratory of the construction site, the samples might gate cooled to lower than the compaction temperature and the mixture must be reheated to compaction temperature and remolded as necessary tests procedures require.

Therefore, the reheating and remolding effect shall be investigated by storing the mixture to 0hrs, 5hrs, 12hrs, 24hrs and 48hrs in the laboratory and let the mixture to cool lower than the compaction temperature and reheating the mixture to compaction temperature again to run the required tests. Five samples of three per are prepared based on the mix design performed and the OBC shall be used to prepare the mixture and the results are evaluated hereunder;

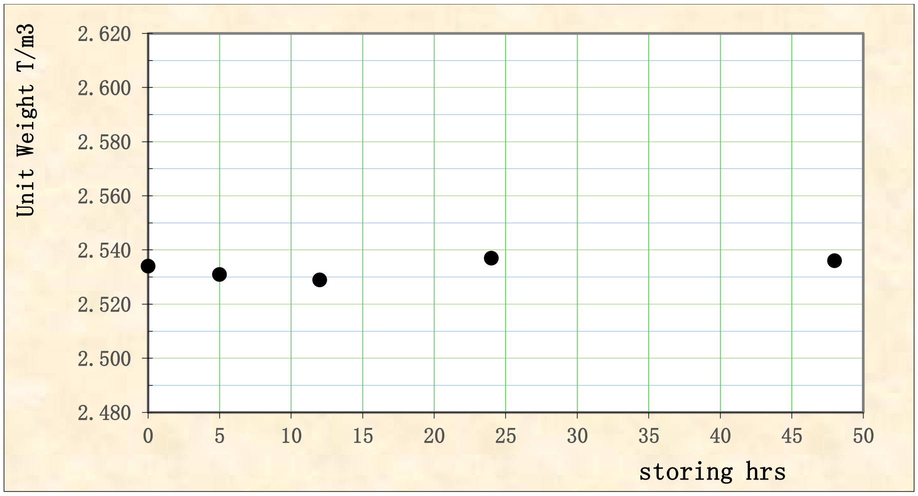

Figure 4.13; storing time Vs Unit weight

The reheated HMA unit weight shown above has no significant difference as we can see from the above chart

The unit weight determined by cooling at a different storing hours after reheating of HMA does not have significant difference as it is shown on the above chart. Therefore cooling and reheating and remolding of hot mix asphalt for different purpose shall be possible hence the mix property is not changed then. In addition the HMA sampled from any working place shall be transferred to any central laboratory at any time then tests shall be processed one by one by reheating, quartering, and remolding as it is necessary.

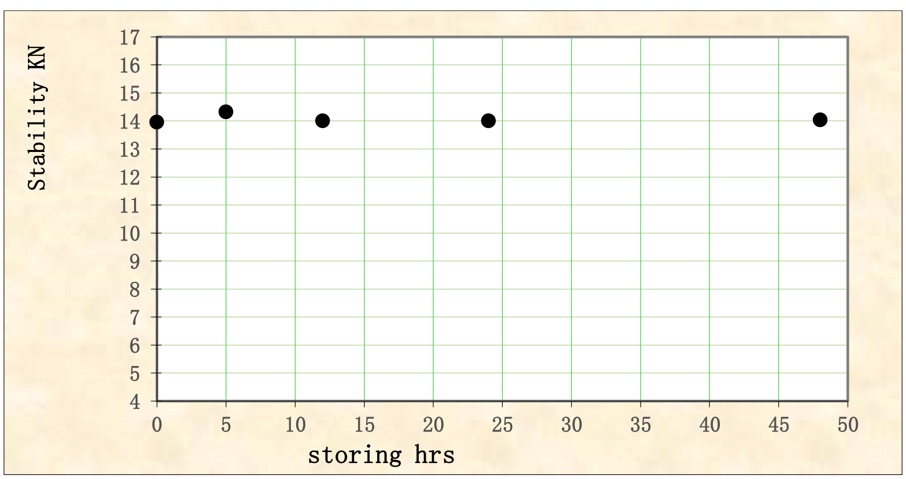

Figure 4.14; Storing time Vs Stability

From above chart the stability of hot mix asphalt determined at different storing time plus reheated to compaction temperature and analyzed above has no significant difference.

This shows that any cooled asphalt at reasonable hours shall be re heated and remolded to determine its physical property.

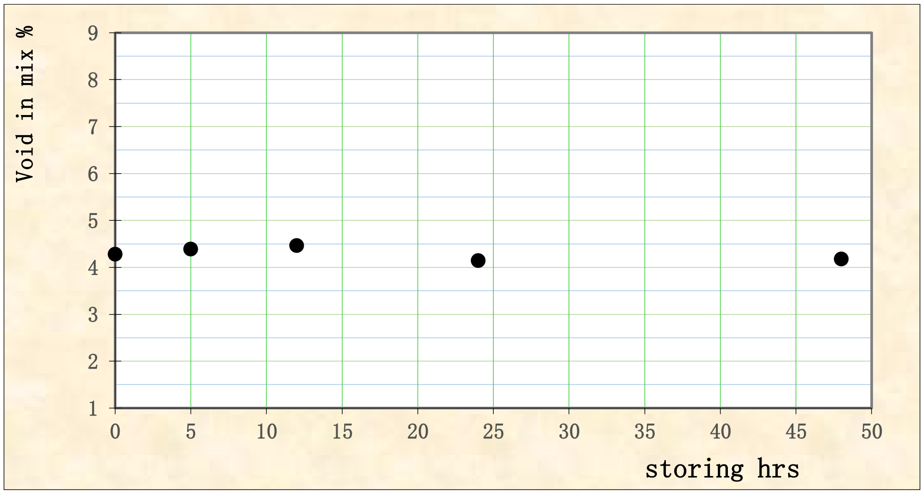

Figure 4.15; Storing time Vs Air Void

Air Void is one of volumetric property determined in hot mix asphalt test analysis. As it is shown from the above chart the void in mix has no significant deference at a different temperature of cooling and reheating i.e the reasonable storing hours doesn't have any significant effect on the air void in mix determination.

Therefore, anyone can determine the mixture volumetric property of cooled HMA by reheating.

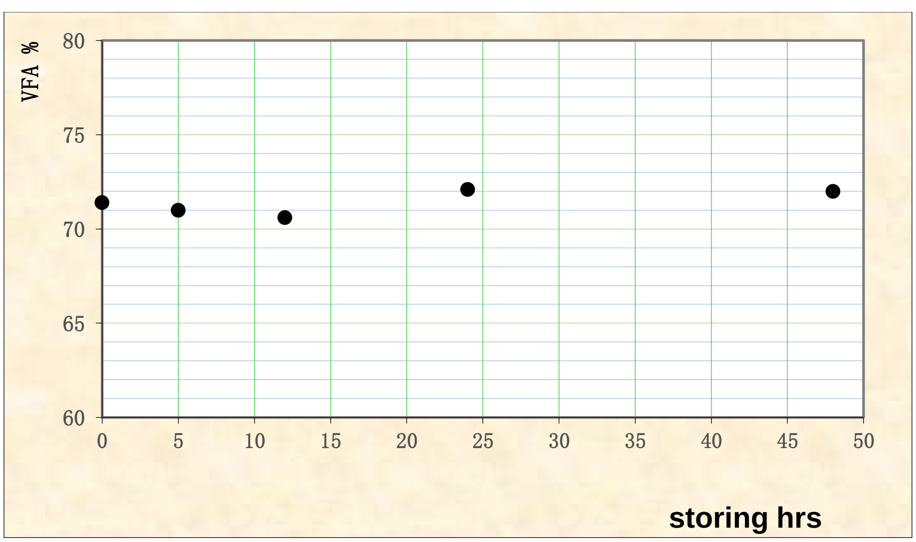

Figure 4.16; Storing time Vs VFA

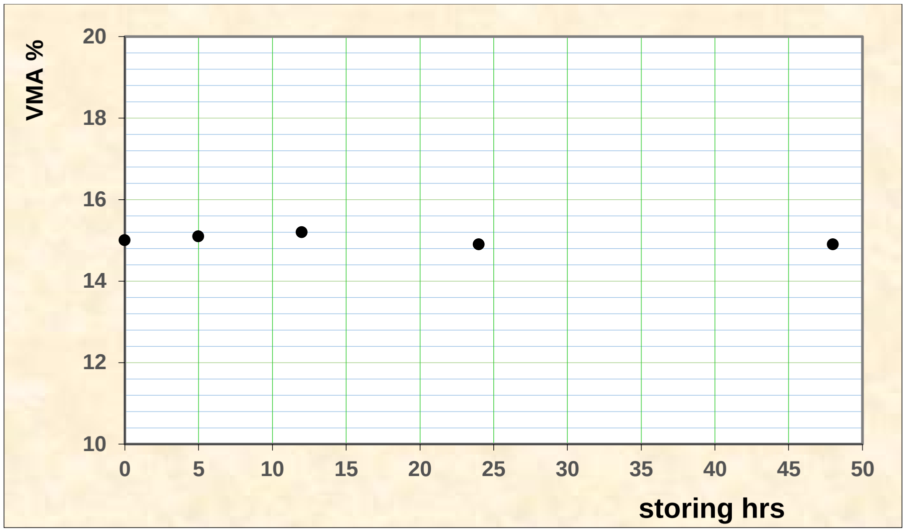

Figure 4.17; Storing time Vs VMA

The void filled with asphalt and void in mineral aggregate are one of volumetric parameters to be determined in HMA according to Marshall Property. As it is seen on above chart both VMA and VFA determined at different storing hours becomes significant difference.

Chapter 5

Conclusion and Recommendation

5.1. Conclusion

The effect of temperature on the property of hot mix asphalt was investigated and different results are collected. From the research conducted the effect of temperature on compaction hot mix asphalt and reheating of asphalt concrete the following conclusions are drawn.

- To study effect of Temperature on HMA compaction eleven per of samples are tested at a different compaction temperature starting from 60°C – 160°C. Prior to this study the mix design has been done for comparison of the effects of compaction temperature. The HMA mix design has been compacted at recommended temperature 145°C. To study the effects unit weight, Void in mineral Aggregate, Void filed with asphalt, Stability and flow testes has been done and analyzed on the previous chapter. From the analyses it has been seen that the there is no significant effect has been found on the parameters defined above. This mean that the temperature variation couldn’t have significant effect on the quality parameters and the variations on the parameters are failed on the tolerance range. The core point for asphalt pavement and the parameter simply affected during construction is void in mix; and the stability.
- It reached on conclusions that when the compaction temperature increases from 60°C to 160°C the unit weight, Stability and Void field with Asphalt simultaneously increases. Whereas, Air void in bitumen mix, Void in mineral and Flow slightly decreases.
- Furthermore, during placement of concrete the effect of compaction temperature could not be observed immediately, whereas the site engineers should not let the temperature of hot mix bitumen drop less than the acceptable range. Hence all the mixture quality parameters are qualifying from 60°c to 160°c.
- It so concluded that the increment of Hot Mix Asphalt temperature is highly useful for the workability of the mix. Hence the viscosity of the mixture is basically depends on the temperature of the Bituminous material. Therefore, the basic parameters are in a range of acceptance for the mixture whenever the mixtures are prepared at a recommended mixing

temperature and compaction can be fulfilled at a different temperature that are cross checked by this research. Prior to implementation several researches has to be done concerning this

- The reheating and remolding investigation is concluded as the compaction temperature is attained, bitumen mixture can be cooled to any temperature for only laboratory testing only.
- Reheating and remolding can be done in the laboratory with proper care of contaminations from surplus material.

5.2. Recommendation

Effect of reheating and remolding is studied on the laboratory sample only that means the lab sample collected from paving site or from mixing plant has been could to less than compaction temperature and reheated to compaction temperature has significant difference with a normal procedure therefore it is recommended this should be practically verified on site field operation and new technique of paving after reheating can be practicable.

In the same manner concerning the compaction temperature this study proofs that, there is no significant difference on the compaction temperature studied from 60 to 160^{o}C. Therefore, it is recommended that this study has to be supported with practical operational study for the sake of practicing new findings and having droughts' on the paved road.

Additionally, as it has seen this thesis if fully concentrated on operation condition which can simplify working methodology. Therefore, it is recommended that this paper has to be verified by further investigational research before practicing.

Furthermore, it is recommended that the study of hot mix asphalt should be included in the curriculum higher education institute as of building design. So that, every civil graduate shall have a basic knowledge on hot mix asphalt mix design preparation paving and studding in addition to small skill gap filling trainings.

Concerning the reheating and remolding this study found out that, there is no significant effect is observed on the results. Therefore, any sample can cooled to any temperature and can be reheated to compaction temperature.

However, the study was proofed only in the laboratory so it is recommended to be verified by conducting further investigation for practical applications.

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Sieve Analysis of Fine and Coarse Aggregate

Test Method AASHTO T- 27

Sample Location :	***Asphalt plant at Ageremariam offset 18Km to Gedeb (HOT Bin)***	*Material For :*	***Asphalt Concrete -- Bin # 1 (25 ~ 17 mm)***
Source :	***Quarry site at Ageremariam offset 8Km to Shakiso***	*Sampling date:*	***12/01/16***
Visual Description :	***Crushed Aggregate (Dark Grey Basalt)***	*Testing Date :*	***14/1/2016***

	Trial #1			Trial #2			Trial #3			Trial #4			Trial #5		
Sieve Sizes (mm)	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**
26.5	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**
19.00	4518.0	33.2	**66.8**	5090.0	35.6	**64.4**	5339.0	35.5	**64.5**	4952.0	35.0	**65.0**	4077.0	36.6	**63.4**
13.20	8942.0	65.8	**1.0**	9071.0	63.4	**1.1**	9542.0	63.5	**0.9**	9042.0	63.9	**1.1**	6939.0	62.4	**1.0**
9.50	90.0	0.7	**0.3**	117.0	0.8	**0.3**	104.0	0.7	**0.2**	119.0	0.8	**0.3**	82.0	0.7	**0.3**
4.75	41.0	0.3	**0.0**	37.0	0.3	**0.0**	35.0	0.2	**0.0**	36.0	0.3	**0.0**	22.0	0.2	**0.1**
2.36	4.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	6.0	0.1	**0.0**
1.18	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**
0.600	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**
0.300	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**
0.150	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**
0.075	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**
Pan	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**
Total	**13595.0**	100.0		**14315.0**	100.0		**15020.0**	100.0		**14149.0**	100.0		**11126.0**	100.0	

Sieve Analysis of Fine and Coarse Aggregate

Test Method AASHTO T- 27

Sample Location :	***Asphalt plant at Ageremariam offset 18Km to Gedeb (HOT Bin)***	*Material For :*	***Asphalt Concrete -- Bin # 1 (25 ~ 17 mm)***
Source :	***Quarry site at Ageremariam offset 8Km to Shakiso***	*Sampling date:*	***12/01/16***
Visual Description :	***Crushed Aggregate (Dark Grey Basalt)***	*Testing Date :*	***14/1/2016***

	Trial #6			Trial #7			Trial #8							
Sieve Sizes (mm)	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**				**Average (%) Retained**	**Average (%) Passing**
26.5	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**				**0.0**	**100.0**
19.00	4361.0	35.9	**64.1**	4444.0	38.6	**61.4**	3818.0	34.3	**65.7**				**35.6**	**64.4**
13.20	7641.0	63.0	**1.1**	6955.0	60.5	**0.9**	7192.0	64.6	**1.1**				**63.4**	**1.0**
9.50	90.0	0.7	**0.3**	54.0	0.5	**0.4**	85.0	0.8	**0.3**				**0.7**	**0.3**
4.75	31.0	0.3	**0.1**	41.0	0.4	**0.1**	28.0	0.3	**0.1**				**0.3**	**0.0**
2.36	8.0	0.1	**0.0**	8.0	0.1	**0.0**	8.0	0.1	**0.0**				**0.0**	**0.0**
1.18	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.0**	**0.0**
0.600	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.0**	**0.0**
0.300	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.0**	**0.0**
0.150	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.0**	**0.0**
0.075	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.0**	**0.0**
Pan	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.0**	**0.0**
Total	**12131.0**	100.0		**11502.0**	100.0		**11131.0**	100.0						

Sieve Analysis of Fine and Coarse Aggregate

Test Method AASHTO T- 27

Sample Location :	***Asphalt plant at Ageremariam offset 18Km to Gedeb (HOT Bin)***	*Material For :*	***Asphalt Concrete -- Bin # 2 (17 ~ 10 mm)***
Source :	***Quarry site at Ageremariam offset 8Km to Shakiso***	*Sampling date:*	***12/01/16***
Visual Description :	***Crushed Aggregate (Dark Grey Basalt)***	*Testing Date :*	***15/1/2016***

	Trial #1			Trial #2			Trial #3			Trial #4			Trial #5		
Sieve Sizes (mm)	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**
26.5	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**
19.00	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**
13.20	5015.0	42.0	**58.0**	4577.0	41.8	**58.2**	5166.0	44.1	**55.9**	5025.0	43.8	**56.2**	4130.0	46.5	**53.5**
9.50	6451.0	54.0	**4.0**	5867.0	53.5	**4.7**	6009.0	51.3	**4.5**	5965.0	52.0	**4.3**	4322.0	48.7	**4.8**
4.75	227.0	1.9	**2.1**	492.0	4.5	**0.2**	505.0	4.3	**0.2**	463.0	4.0	**0.2**	394.0	4.4	**0.3**
2.36	23.0	0.2	**1.9**	23.0	0.2	**0.0**	23.0	0.2	**0.0**	25.0	0.2	**0.0**	22.0	0.2	**0.1**
1.18	0.0	0.0	**1.9**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	4.0	0.0	**0.0**
0.600	0.0	0.0	**1.9**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	3.0	0.0	**0.0**
0.300	0.0	0.0	**1.9**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**
0.150	0.0	0.0	**1.9**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**
0.075	0.0	0.0	**1.9**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**
Pan	226.0	1.9	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**
Total	**11942.0**	100.0		**10959.0**	100.0		**11703.0**	100.0		**11478.0**	129.3		**8875.0**	100.0	

Sieve Analysis of Fine and Coarse Aggregate

Test Method AASHTO T- 27

Sample Location :	***Asphalt plant at Ageremariam offset 18Km to Gedeb (HOT Bin)***	*Material For :*	***Asphalt Concrete -- Bin # 2 (17 ~ 10 mm)***
Source :	***Quarry site at Ageremariam offset 8Km to Shakiso***	*Sampling date:*	***12/01/16***
Visual Description :	***Crushed Aggregate (Dark Grey Basalt)***	*Testing Date :*	***15/1/2016***

	Trial #6			Trial #7			Trial #8							
Sieve Sizes (mm)	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**				**Average (%) Retained**	**Average (%) Passing**
26.5	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**				**0.0**	**100.0**
19.00	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**				**0.0**	**100.0**
13.20	4409.0	48.3	**51.7**	4065.0	44.8	**55.2**	3806.0	42.9	**57.1**				**44.3**	**55.7**
9.50	4269.0	46.8	**5.0**	4480.0	49.4	**5.7**	4608.0	51.9	**5.2**				**51.0**	**4.8**
4.75	423.0	4.6	**0.3**	491.0	5.4	**0.3**	429.0	4.8	**0.3**				**4.3**	**0.5**
2.36	22.0	0.2	**0.1**	21.0	0.2	**0.1**	24.0	0.3	**0.1**				**0.2**	**0.3**
1.18	3.0	0.0	**0.0**	4.0	0.0	**0.1**	4.0	0.0	**0.0**				**0.0**	**0.3**
0.600	4.0	0.0	**0.0**	5.0	0.1	**0.0**	3.0	0.0	**0.0**				**0.0**	**0.2**
0.300	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.0**	**0.2**
0.150	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.0**	**0.2**
0.075	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.0**	**0.2**
Pan	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.2**	**0.0**
Total	**9130.0**	100.0		**9066.0**	100.0		**8874.0**	100.0						

Sieve Analysis of Fine and Coarse Aggregate

Test Method AASHTO T- 27

Sample Location :	***Asphalt plant at Ageremariam offset 18Km to Gedeb (HOT Bin)***	*Material For :*	***Asphalt Concrete -- Bin # 3 (10 ~ 5mm)***
Source :	***Quarry site at Ageremariam offset 8Km to Shakiso***	*Sampling date:*	***12/01/16***
Visual Description :	***Crushed Aggregate (Dark Grey Basalt)***	*Testing Date :*	***16/1/2016***

	Trial #1			Trial #2			Trial #3			Trial #4			Trial #5		
Sieve Sizes (mm)	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**
26.5	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**
19.00	0	0.0	**100.0**	0	0.0	**100.0**	12	0.2	**99.8**	0	0.0	**100.0**	0	0.0	**100.0**
13.20	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**99.8**	0.0	0.0	**100.0**	0.0	0.0	**100.0**
9.50	179.0	2.4	**97.6**	192.0	2.5	**97.5**	221.0	2.9	**96.9**	34.0	0.5	**99.5**	185.0	2.1	**97.9**
4.75	6809	92.9	**4.7**	7098	92.0	**5.5**	6930	91.6	**5.3**	6969	94.1	**5.4**	8286	94.3	**3.6**
2.36	178.0	2.4	**2.3**	248.0	3.2	**2.3**	225.0	3.0	**2.3**	221.0	3.0	**2.4**	267.0	3.0	**0.6**
1.18	60.0	0.8	**1.4**	63.0	0.8	**1.5**	65.0	0.9	**1.5**	65.0	0.9	**1.5**	37.0	0.4	**0.2**
0.600	50.0	0.7	**0.8**	51.0	0.7	**0.8**	50.0	0.7	**0.8**	39.0	0.5	**1.0**	9.0	0.1	**0.1**
0.300	28.0	0.4	**0.4**	32.0	0.4	**0.4**	32.0	0.4	**0.4**	45.0	0.6	**0.4**	4.0	0.0	**0.0**
0.150	16.0	0.2	**0.2**	17.0	0.2	**0.2**	17.0	0.2	**0.2**	15.0	0.2	**0.2**	1.0	0.0	**0.0**
0.075	8.0	0.1	**0.1**	8.0	0.1	**0.1**	8.0	0.1	**0.1**	9.0	0.1	**0.1**	1.0	0.0	**0.0**
Pan	4.0	0.1	**0.0**	5.0	0.1	**0.0**	5.0	0.1	**0.0**	6.0	0.1	**0.0**	0.0	0.0	**0.0**
Total	**7332.0**	100.0		**7714.0**	100.0		**7565.0**	100.0		**7403.0**	100.0		**8790.0**	100.0	

Sieve Analysis of Fine and Coarse Aggregate

Test Method AASHTO T- 27

Sample Location :	***Asphalt plant at Ageremariam offset 18Km to Gedeb (HOT Bin)***	*Material For :*	***Asphalt Concrete -- Bin # 3 (10 ~ 5mm)***
Source :	***Quarry site at Ageremariam offset 8Km to Shakiso***	*Sampling date:*	***12/01/16***
Visual Description :	***Crushed Aggregate (Dark Grey Basalt)***	*Testing Date :*	***16/1/2016***

	Trial #6			Trial #7			Trial #8							
Sieve Sizes (mm)	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**				**Average (%) Retained**	**Average (%) Passing**
26.5	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**				**0.0**	**100.0**
19.00	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**				**0.0**	**100.0**
13.20	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**				**0.0**	**100.0**
9.50	162.0	1.9	**98.1**	188.0	2.0	**98.0**	242.0	2.7	**97.3**				**2.1**	**97.9**
4.75	8222	94.5	**3.6**	8855	94.8	**3.1**	8555	94.6	**2.8**				**93.6**	**4.3**
2.36	260.0	3.0	**0.6**	243.0	2.6	**0.5**	193.0	2.1	**0.6**				**2.8**	**1.5**
1.18	42.0	0.5	**0.1**	36.0	0.4	**0.1**	38.0	0.4	**0.2**				**0.6**	**0.8**
0.600	8.0	0.1	**0.1**	8.0	0.1	**0.1**	11.0	0.1	**0.1**				**0.4**	**0.5**
0.300	4.0	0.0	**0.0**	3.0	0.0	**0.0**	3.0	0.0	**0.0**				**0.2**	**0.2**
0.150	1.0	0.0	**0.0**	3.0	0.0	**0.0**	2.0	0.0	**0.0**				**0.1**	**0.1**
0.075	0.0	0.0	**0.0**	0.0	0.0	**0.0**	2.0	0.0	**0.0**				**0.1**	**0.0**
Pan	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.0**	**0.0**
Total	**8699.0**	100.0		**9336.0**	100.0		**9046.0**	100.0						

Sieve Analysis of Fine and Coarse Aggregate

Test Method AASHTO T- 27

Sample Location :	***Asphalt plant at Ageremariam offset 18Km to Gedeb (HOT Bin)***	*Material For :*	***Asphalt Concrete -- Bin # 4 (5 ~ 3 mm)***
Source :	***Quarry site at Ageremariam offset 8Km to Shakiso***	*Sampling date:*	***12/01/16***
Visual Description :	***Crushed Aggregate (Dark Grey Basalt)***	*Testing Date :*	***17/1/2016***

	Trial #1			Trial #2			Trial #3			Trial #4			Trial #5		
Sieve Sizes (mm)	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**
26.5	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**
19.00	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**
13.20	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**
9.50	40.0	0.5	**99.5**	23.0	0.3	**99.7**	36.0	0.5	**99.5**	34.0	0.5	**99.5**	50.0	0.6	**99.4**
4.75	264	3.5	**95.9**	310	4.1	**95.6**	324	4.3	**95.2**	270	3.7	**95.9**	282	3.6	**95.8**
2.36	7131.0	95.5	**0.4**	7188.0	95.1	**0.5**	7148.0	94.7	**0.5**	6978.0	95.2	**0.6**	7473.0	95.3	**0.5**
1.18	22.0	0.3	**0.1**	24.0	0.3	**0.2**	21.0	0.3	**0.2**	26.0	0.4	**0.3**	27.0	0.3	**0.1**
0.600	10.0	0.1	**0.0**	9.0	0.1	**0.1**	10.0	0.1	**0.1**	10.0	0.1	**0.1**	8.0	0.1	**0.0**
0.300	0.0	0.0	**0.0**	0.0	0.0	**0.1**	5.0	0.1	**0.0**	4.0	0.1	**0.1**	3.0	0.0	**0.0**
0.150	0.0	0.0	**0.0**	6.0	0.1	**0.0**	3.0	0.0	**0.0**	6.0	0.1	**0.0**	0.0	0.0	**0.0**
0.075	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**
Pan	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**
Total	**7467.0**	100.0		**7560.0**	100.0		**7547.0**	100.0		**7328.0**	100.0		**7843.0**	100.0	

Sieve Analysis of Fine and Coarse Aggregate

Test Method AASHTO T- 27

Sample Location :	***Asphalt plant at Ageremariam offset 18Km to Gedeb (HOT Bin)***	*Material For :*	***Asphalt Concrete -- Bin # 4 (5 ~ 3 mm)***
Source :	***Quarry site at Ageremariam offset 8Km to Shakiso***	*Sampling date:*	***12/01/16***
Visual Description :	***Crushed Aggregate (Dark Grey Basalt)***	*Testing Date :*	***17/1/2016***

	Trial #6			Trial #7			Trial #8							
Sieve Sizes (mm)	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**				**Average (%) Retained**	**Average (%) Passing**
26.5	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**				**0.0**	**100.0**
19.00	0	0.0	**100.0**	0	0.0	**100.0**	0	0.0	**100.0**				**0.0**	**100.0**
13.20	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**				**0.0**	**100.0**
9.50	45.0	0.5	**99.5**	54.0	0.7	**99.3**	31.0	0.4	**99.6**				**0.5**	**99.5**
4.75	287	3.4	**96.0**	274	3.5	**95.8**	269	3.3	**96.3**				**3.7**	**95.8**
2.36	8031.0	95.6	**0.4**	7484.0	95.3	**0.5**	7838.0	95.8	**0.5**				**95.3**	**0.5**
1.18	25.0	0.3	**0.1**	30.0	0.4	**0.1**	31.0	0.4	**0.1**				**0.3**	**0.2**
0.600	8.0	0.1	**0.0**	8.0	0.1	**0.0**	7.0	0.1	**0.0**				**0.1**	**0.1**
0.300	4.0	0.0	**0.0**	3.0	0.0	**0.0**	4.0	0.0	**0.0**				**0.0**	**0.0**
0.150	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.0**	**0.0**
0.075	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.0**	**0.0**
Pan	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**				**0.0**	**0.0**
Total	**8400.0**	100.0		**7853.0**	100.0		**8180.0**	100.0						

Sieve Analysis of Fine and Coarse Aggregate

Test Method AASHTO T- 27

Sample Location :	***Asphalt plant at Ageremariam offset 18Km to Gedeb (HOT Bin)***	*Material For :*	***Asphalt Concrete -- Bin # 5 (3~ 0 mm)***
Source :	***Quarry site at Ageremariam offset 8Km to Shakiso***	*Sampling date:*	***12/01/16***
Visual Description :	***Crushed Aggregate (Dark Grey Basalt)***	*Testing Date :*	***18/1/2016***

	Trial #1			Trial #2			Trial #3			Trial #4			Trial #5		
Sieve Sizes (mm)	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**
26.5	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**
19.00	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**
13.20	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**
9.50	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**
4.75	0.0	0.0	**100.0**	0.0	0.0	**100.0**	38.0	1.0	**99.0**	42.0	1.1	**98.9**	0.0	0.0	**100.0**
2.36	533.0	10.8	**89.2**	593.0	12.2	**87.8**	701.0	18.5	**80.5**	809.0	20.9	**78.0**	644.0	13.2	**86.8**
1.18	1713.0	34.9	**54.3**	1596.0	32.9	**54.8**	1098.0	28.9	**51.6**	1046.0	27.0	**51.0**	1605.0	32.9	**53.9**
0.600	845.0	17.2	**37.1**	867.0	17.9	**36.9**	495.0	13.0	**38.6**	468.0	12.1	**38.9**	797.0	16.3	**37.6**
0.300	1160.0	23.6	**13.5**	1155.0	23.8	**13.1**	703.0	18.5	**20.1**	712.0	18.4	**20.4**	1212.0	24.8	**12.8**
0.150	435.0	8.9	**4.6**	467.0	9.6	**3.5**	419.0	11.0	**9.0**	429.0	11.1	**9.4**	408.0	8.4	**4.4**
0.075	129.0	2.6	**2.0**	97.0	2.0	**1.5**	185.0	4.9	**4.2**	189.0	4.9	**4.5**	130.0	2.7	**1.8**
Pan	98.0	2.0	**0.0**	71.0	1.5	**0.0**	158.0	4.2	**0.0**	173.0	4.5	**0.0**	87.0	1.8	**0.0**
Total	**4913.0**	100.0		**4846.0**	100.0		**3797.0**	100.0		**3868.0**	100.0		**4883.0**	100.0	

Sieve Analysis of Fine and Coarse Aggregate

Test Method AASHTO T- 27

Sample Location :	***Asphalt plant at Ageremariam offset 18Km to Gedeb (HOT Bin)***	*Material For :*	***Asphalt Concrete -- Bin # 5 (3~ 0 mm)***
Source :	***Quarry site at Ageremariam offset 8Km to Shakiso***	*Sampling date:*	***12/01/16***
Visual Description :	***Crushed Aggregate (Dark Grey Basalt)***	*Testing Date :*	***18/1/2016***

	Trial #6			Trial #7			Trial #8				
Sieve Sizes (mm)	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Average (%) Retained**	**Average (%) Passing**
26.5	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	**0.0**	**100.0**
19.00	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	**0.0**	**100.0**
13.20	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	**0.0**	**100.0**
9.50	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	**0.0**	**100.0**
4.75	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	**0.3**	**99.7**
2.36	499.0	11.7	**88.3**	550.0	11.6	**88.4**	511.0	10.8	**89.2**	**13.7**	**86.0**
1.18	1394.0	32.7	**55.5**	1584.0	33.5	**54.9**	1500.0	31.6	**57.6**	**31.8**	**54.2**
0.600	1056.0	24.8	**30.7**	1120.0	23.7	**31.3**	855.0	18.0	**39.6**	**17.9**	**36.3**
0.300	753.0	17.7	**13.0**	840.0	17.7	**13.5**	1252.0	26.4	**13.2**	**21.4**	**15.0**
0.150	373.0	8.8	**4.3**	431.0	9.1	**4.4**	447.0	9.4	**3.8**	**9.5**	**5.4**
0.075	123.0	2.9	**1.4**	128.0	2.7	**1.7**	115.0	2.4	**1.4**	**3.1**	**2.3**
Pan	59.0	1.4	**0.0**	82.0	1.7	**0.0**	66.0	1.4	**0.0**	**2.3**	**0.0**
Total	**4257.0**	100.0		**4735.0**	100.0		**4746.0**	100.0			

Sieve Analysis of Fine and Coarse Aggregate

Test Method AASHTO T- 27

Sample Location :	***Asphalt plant at Ageremariam offset 18Km to Gedeb (HOT Bin)***	Material For :	***Asphalt Concrete -- Stone Dust***
Source :	***Quarry site at Ageremariam offset 8Km to Shakiso***	Sampling date:	***12/01/16***
Visual Description :	***Crushed Aggregate (Dark Grey Basalt)***	Testing Date :	***19/1/2016***

	Trial #1			Trial #2			Trial #3			Trial #4				
Sieve Sizes (mm)	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Average (%) Retained**	**Average (%) Passing**
26.5	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
19.00	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
13.20	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
9.50	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
4.75	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
2.36	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
1.18	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
0.600	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
0.300	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
0.150	50.0	6.7	**93.3**	36.0	5.8	**94.2**	35.0	5.8	**94.2**	34.0	5.4	**94.6**	5.9	94.1
0.075	146.0	19.4	**73.9**	124.0	20.1	**74.1**	120.0	20.0	**74.2**	150.0	23.8	**70.8**	20.8	73.2
Pan	555.0	73.9	**0.0**	457.0	74.1	**0.0**	446.0	74.2	**0.0**	446.0	70.8	**0.0**	73.2	0.0
Total	**751.0**	100.0		**617.0**	100.0		**601.0**	100.0		**630.0**	100.0			

Sieve Analysis of Fine and Coarse Aggregate

Test Method AASHTO T- 27

Sample Location :	***Asphalt plant at Ageremariam offset 18Km to Gedeb (HOT Bin)***	*Material For :*	***Asphalt Concrete -- Mineral Filler***
Source :	***Quarry site at Ageremariam offset 8Km to Shakiso***	*Sampling date:*	***12/01/16***
Visual Description :	***Crushed Aggregate (Dark Grey Basalt)***	*Testing Date :*	***20/1/2016***

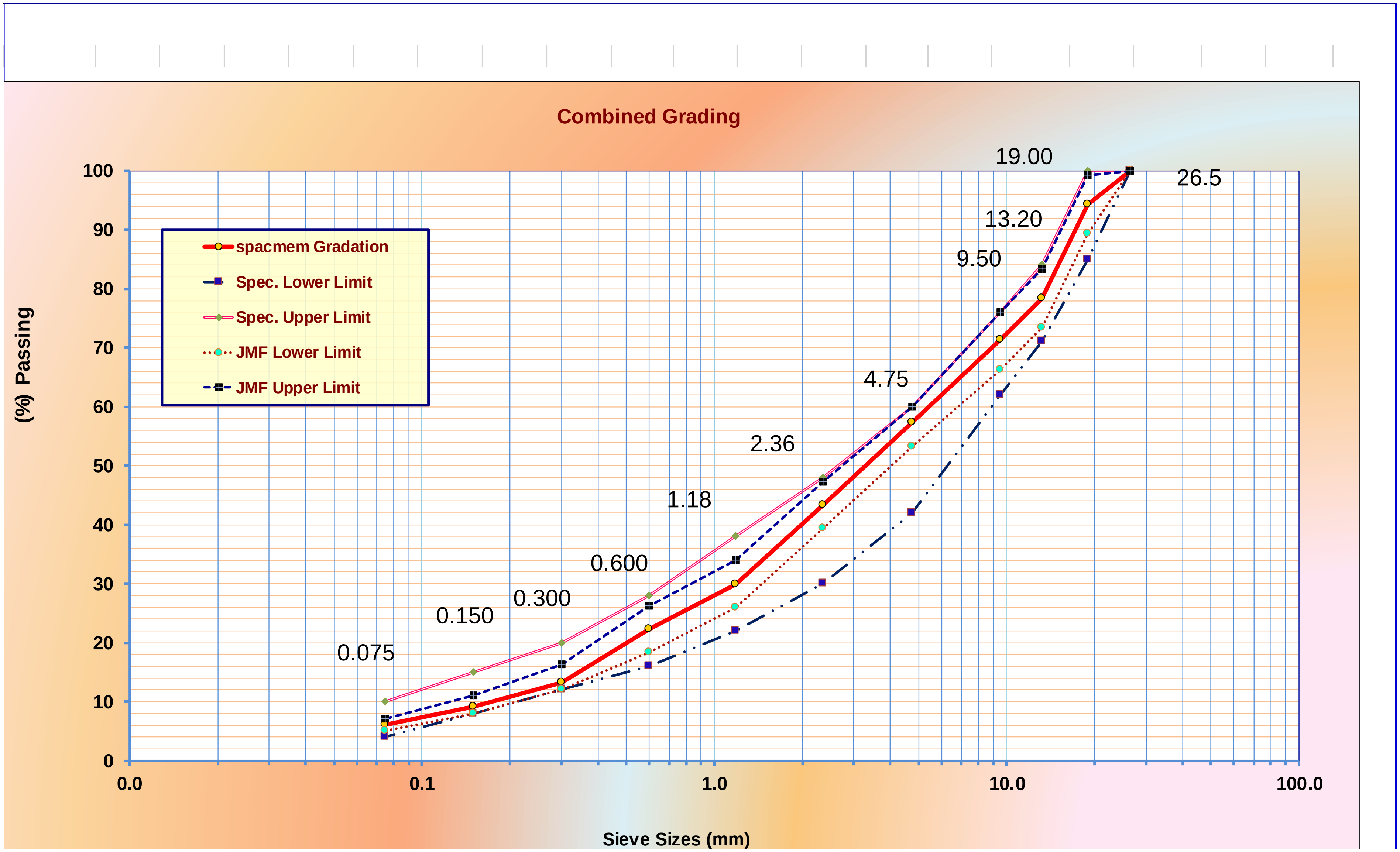
	Trial #1			Trial #2			Trial #3			Trial #4				
Sieve Sizes (mm)	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Weight Retained**	**% Retained**	**% Passing**	**Average (%) Retained**	**Average (%) Passing**
26.5	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
19.00	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
13.20	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
9.50	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
4.75	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
2.36	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
1.18	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
0.600	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
0.300	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	0.0	**100.0**	0.0	100.0
0.150	9.0	1.3	**98.7**	10.0	1.3	**98.7**	6.0	1.0	**99.0**	7.0	1.1	**98.9**	1.2	98.8
0.075	166.0	24.6	**74.1**	206.0	26.8	**71.9**	148.0	24.5	**74.5**	157.0	24.8	**74.1**	25.2	73.6
Pan	501.0	74.1	**0.0**	554.0	71.9	**0.0**	449.0	74.5	**0.0**	468.0	74.1	**0.0**	73.6	0.0
Total	**676.0**	100.0		**770.0**	100.0		**603.0**	100.0		**632.0**	100.0			

Represented Section :	*Asphalt plant at Ageremariam offset 18Km to Gedeb (HOT Bin)*	*Material For :*	*Asphalt ConcreteMix Design*
Source :	*Quarry site at Ageremariam offset 8Km to Shakiso*	*Sampling date:*	*05/01/16*
Visual Description :	*Crushed Aggregate*	*Testing Date :*	*21/01/16*

Hot Bin (persent passing)

Sieve Sizes (mm)	Bin # 1	Pro. % 16	Bin # 2	Pro. % 13	Bin # 3	Pro. % 14	Bin # 4	Pro. % 8	Bin # 5	Pro. % 42	Stone Dust	Pro. % 4	Mineral Filler	Pro. % 3	Combined Grading	Median of the Spec.	Tolerance Limit Lower	Tolerance Limit Upper	Spec Limit Lower	Spec Limit Upper
26.5	100.0	16.0	**100.0**	13.0	100.0	**14.0**	100.0	**8.0**	**100.0**	42.0	100.0	**4.0**	**100.0**	3.0	100.0	**100.0**	**100**	**100**	**100**	**100**
19.00	64.4	10.3	**100.0**	13.0	100.0	**14.0**	100.0	8.0	**100.0**	42.0	100.0	4.0	**100.0**	3.0	94.3	**92.5**	**89**	**99**	**85**	**100**
13.20	1.0	0.2	**55.7**	7.2	100.0	**14.0**	100.0	8.0	**100.0**	42.0	100.0	4.0	**100.0**	3.0	78.4	**77.5**	**73**	**83**	**71**	**84**
9.50	0.3	0.0	**4.8**	0.6	97.9	**13.7**	99.5	8.0	**100.0**	42.0	100.0	4.0	**100.0**	3.0	71.3	**69.0**	**66**	**76**	**62**	**76**
4.75	0.0	0.0	**0.5**	0.1	4.3	**0.6**	95.8	7.7	**99.7**	41.9	100.0	4.0	**100.0**	3.0	57.3	**51.0**	**53**	**60**	**42**	**60**
2.36	0.0	0.0	**0.3**	0.0	1.5	**0.2**	0.5	0.0	**86.0**	36.1	100.0	4.0	**100.0**	3.0	43.3	**39.0**	**39**	**47**	**30**	**48**
1.18	0.0	0.0	**0.3**	0.0	0.8	**0.1**	0.2	0.0	**54.2**	22.8	100.0	4.0	**100.0**	3.0	29.9	**30.0**	**26**	**34**	**22**	**38**
0.600	0.0	0.0	**0.2**	0.0	0.5	**0.1**	0.1	0.0	**36.3**	15.2	100.0	4.0	**100.0**	3.0	22.3	**22.0**	**18**	**26**	**16**	**28**
0.300	0.0	0.0	**0.2**	0.0	0.2	**0.0**	0.0	0.0	**15.0**	6.3	100.0	4.0	**100.0**	3.0	13.3	**16.0**	**12**	**16**	**12**	**20**
0.150	0.0	0.0	**0.2**	0.0	0.1	**0.0**	0.0	0.0	**5.4**	2.3	94.1	3.8	**98.8**	3.0	9.1	**11.5**	**8**	**11**	**8**	**15**
0.075	0.0	0.0	**0.2**	0.0	0.0	**0.0**	0.0	0.0	**2.3**	1.0	73.2	2.9	**73.6**	2.2	6.1	**7.0**	**5**	**7**	**4**	**10**
Pan	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0						

Remarks :



Combined Grading
(%) Passing
Sieve Sizes (mm)
spacmem Gradation
Spec. Lower Limit
Spec. Upper Limit
JMF Lower Limit
JMF Upper Limit
0.075
0.150
0.300
0.600
1.18
2.36
4.75
9.50
13.20
19.00
26.5
0
10
20
30
40
50
60
70
80
90
100
0.0
0.1
1.0
10.0
100.0

Appendix B

THEORETICAL MAXIMUM SPCIFIC GRAVITY OF BITUMINOUS PAVING MIXTURE (Gmm)

TEST METHOD: ASTM DESGNATION:D 2041-90

MATERIAL FOR SAMPLE	**AC WC MIX DESIGN**	DATE OF SAMPLING	**05/02/16**
SOURCE OF AGGREGATE	**Asphalt plant at Ageremariam offset 18Km to Ge**	DATE OF TESTING	**08/02/16**
SOURCE OF BITUMEN	**60/70 Pen. Grade**	ASPHALT CONTENT	**4.40%**
TYPE OF MIX	**TRIAL MIX DESIGN -- Hot Bin**	SAMPLE REFERENCE	**20**

MASS OF THE JAR		
A. MASS OF DRY SAMPLE IN AIR	1256	1258
B. MASS OF JAR FILLED WITH WATER	19001	19001
C. MASS OF JAR FILLED WITH WATER+SAMPLE	19799	19801
WATER TEMPRATURE	**24 °C**	

°C	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
K	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0003	1.0000	0.9997	0.9995	0.9992	0.9989

K . WATER TEMPRATURE CORECTION	1.0003	1.0003
MAXIMUM THEORETEICAL SPECIFIC GRAVITY = $K * \frac{A}{A+B-C}$	**2.743**	**2.748**
AVERAGE MAXIMUM THEORETICAL SPECIFIC GRAVITY(Gmm)	**2.746**	

REMARKS

THEORETICAL MAXIMUM SPCIFIC GRAVITY OF BITUMINOUS PAVING MIXTURE (Gmm)

TEST METHOD: ASTM DESGNATION:D 2041-90

MATERIAL FOR SAMPLE	**AC WC MIX DESIGN**	DATE OF SAMPLING	**05/02/16**
SOURCE OF AGGREGATE	**Asphalt plant at Ageremariam offset 18Km to Ge**	DATE OF TESTING	**08/02/16**
SOURCE OF BITUMEN	**60/70 Pen. Grade**	ASPHALT CONTENT	**4.70%**
TYPE OF MIX	**TRIAL MIX DESIGN -- Hot Bin**	SAMPLE REFERENCE	**20**

MASS OF THE JAR		
A. MASS OF DRY SAMPLE IN AIR	1269	1264
B. MASS OF JAR FILLED WITH WATER	19001	19001
C. MASS OF JAR FILLED WITH WATER+SAMPLE	19803	19798
WATER TEMPRATURE	**23 °C**	

°C	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
K	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0003	1.0000	0.9997	0.9995	0.9992	0.9989

K . WATER TEMPRATURE CORECTION	1.0005	1.0005
MAXIMUM THEORETEICAL SPECIFIC GRAVITY = $K * \frac{A}{A+B-C}$	**2.719**	**2.708**
AVERAGE MAXIMUM THEORETICAL SPECIFIC GRAVITY(Gmm)	**2.714**	

REMARKS

THEORETICAL MAXIMUM SPCIFIC GRAVITY OF BITUMINOUS PAVING MIXTURE (Gmm)

TEST METHOD: ASTM DESGNATION:D 2041-90

MATERIAL FOR SAMPLE	**AC WC MIX DESIGN**	DATE OF SAMPLING	**05/02/16**
SOURCE OF AGGREGATE	**Asphalt plant at Ageremariam offset 18Km to Ge**	DATE OF TESTING	**08/02/16**
SOURCE OF BITUMEN	**60/70 Pen. Grade**	ASPHALT CONTENT	**5.00%**
TYPE OF MIX	**TRIAL MIX DESIGN -- Hot Bin**	SAMPLE REFERENCE	**20**

MASS OF THE JAR		
A. MASS OF DRY SAMPLE IN AIR	1266	1268
B. MASS OF JAR FILLED WITH WATER	18999	18999
C. MASS OF JAR FILLED WITH WATER+SAMPLE	19787	19787
WATER TEMPRATURE	**22 ^{o}C**	

^{O}C	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
K	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0003	1.0000	0.9997	0.9995	0.9992	0.9989

K . WATER TEMPRATURE CORECTION	1.0007	1.0007
MAXIMUM THEORETEICAL SPECIFIC GRAVITY = $K * \frac{A}{A+B-C}$	**2.650**	**2.644**
AVERAGE MAXIMUM THEORETICAL SPECIFIC GRAVITY(Gmm)	**2.647**	

REMARKS

THEORETICAL MAXIMUM SPCIFIC GRAVITY OF BITUMINOUS PAVING MIXTURE (Gmm)

TEST METHOD: ASTM DESGNATION:D 2041-90

MATERIAL FOR SAMPLE	**AC WC MIX DESIGN**	DATE OF SAMPLING	**05/02/16**
SOURCE OF AGGREGATE	**Asphalt plant at Ageremariam offset 18Km to Ge**	DATE OF TESTING	**08/02/16**
SOURCE OF BITUMEN	**60/70 Pen. Grade**	ASPHALT CONTENT	**5.30%**
TYPE OF MIX	**TRIAL MIX DESIGN -- Hot Bin**	SAMPLE REFERENCE	**20**

MASS OF THE JAR		
A. MASS OF DRY SAMPLE IN AIR	1270	1268
B. MASS OF JAR FILLED WITH WATER	18999	18999
C. MASS OF JAR FILLED WITH WATER+SAMPLE	19786	19789
WATER TEMPRATURE	**22 °C**	

°C	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
K	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0003	1.0000	0.9997	0.9995	0.9992	0.9989

K . WATER TEMPRATURE CORECTION	1.0007	1.0007
MAXIMUM THEORETEICAL SPECIFIC GRAVITY = $K * \frac{A}{A+B-C}$	**2.631**	**2.655**
AVERAGE MAXIMUM THEORETICAL SPECIFIC GRAVITY(Gmm)	**2.643**	

REMARKS

THEORETICAL MAXIMUM SPCIFIC GRAVITY OF BITUMINOUS PAVING MIXTURE (Gmm)

TEST METHOD: ASTM DESGNATION:D 2041-90

MATERIAL FOR SAMPLE	**AC WC MIX DESIGN**	DATE OF SAMPLING	**05/02/16**
SOURCE OF AGGREGATE	**Asphalt plant at Ageremariam offset 18Km to Ge**	DATE OF TESTING	**08/02/16**
SOURCE OF BITUMEN	**60/70 Pen. Grade**	ASPHALT CONTENT	**5.60%**
TYPE OF MIX	**TRIAL MIX DESIGN -- Hot Bin**	SAMPLE REFERENCE	**20**

MASS OF THE JAR		
A. MASS OF DRY SAMPLE IN AIR	1268	1267
B. MASS OF JAR FILLED WITH WATER	19001	19001
C. MASS OF JAR FILLED WITH WATER+SAMPLE	19788	19785
WATER TEMPRATURE	**25 °C**	

°C	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
K	1.0016	1.0014	1.0012	1.0010	1.0007	1.0005	1.0003	1.0000	0.9997	0.9995	0.9992	0.9989

K . WATER TEMPRATURE CORECTION	1.0000	1.0000
MAXIMUM THEORETEICAL SPECIFIC GRAVITY = $K * \frac{A}{A+B-C}$	**2.636**	**2.623**
AVERAGE MAXIMUM THEORETICAL SPECIFIC GRAVITY(Gmm)	**2.630**	

REMARKS

Combined aggregate Specific Gravity (SG) and Maximum Theoretical Specific Gravity (G_{mm}) Calculations.

MATERIAL FOR SAMPLE	AC WC MIX DESIGN	DATE OF SAMPLING	05/02/16
SOURCE OF AGGREGATE	Asphalt plant at Ageremariam offset 18Km to Gedeb (H(	DATE OF TESTING	06/02/16
SOURCE OF BITUMEN	60/70 Pen. Grade	ASPHALT CONTENT	4.4% - 5.6%
TYPE OF MIX	TRIAL MIX DESIGN -- Hot Bin T4	SAMPLE REFERENCE	20

Calculation of Design Bitumen Content:

Sieve Sizes (mm)	% Pass	Cumula. % Retained
26.5	100	0.0
19.00	94.3	5.7
13.20	78.4	21.6
9.50	71.3	28.7
4.75	57.3	42.7
2.36	43.3	56.7
1.18	29.9	70.1
0.600	22.3	77.7
0.300	13.3	86.7
0.150	9.1	90.9
0.075	6.1	93.9
Pan	0.0	100.0
Total	0.0	100.0

DBC = 0.035a + 0.04b + Kc + F

where : *DBC = approximate design bitumen content, per cent by total weight of mix*

a = per cent of mineral aggregate retained on the 2.36mm sieve

b = per cent of mineral aggregate passing the 2.36mm sieve and retained on the 0.075mm sieve

c = per cent of mineral aggregate passing the 0.075mm sieve

K = 0.15 for 11-15% passing the 0.075mm sieve;
0.18 for 6-10% passing the 0.075mm sieve;
0.20 for 5% or less passing the 0.075mm sieve;

F = 0-2%. Based on absorption of bitumen. In the absence of other data, a value of 0.7 is sugg

a	*b*	*K*	C	F
56.70	*37.20*	*0.18*	6.10	0.85

Specific gravity of Bitumen (AC), Gb = **1.026**

G_{se} = **2.893** G_{sb} = **2.825**

Bitumen Absorption (P_{ba})

$$P_{ba} = \frac{100\,(G_{se} - G_{sb})\,G_b}{G_{se}G_{sb}} = 0.85$$

DBC = 5.42

Effective bitumen content of the mix

$$P_{be} = P_b - \frac{P_{ba}\,P_s}{100}$$

Bitumen Content (%)	4.4	4.7	5.0	5.3	5.6
Bulk SG of Specimen (G_{mb})	2.495	2.522	2.529	2.547	2.550
Maximum SG of Loose mix (G_{mm})	**2.679**	**2.665**	**2.652**	**2.639**	**2.626**
Effective bitumen content of the mix (P_{be})	**3.59**	**3.89**	**4.19**	**4.50**	**4.80**

***Combined aggregate Specific Gravity (SG) and Maximum Theoretical Specific Gravity (G_{mm}) Calculations*.**

MATERIAL FOR SAMPLE	AC WC MIX DESIGN	DATE OF SAMPLING	**05/02/16**
SOURCE OF AGGREGATE	Asphalt plant at Ageremariam offset 18Km to Gedeb (H	DATE OF TESTING	**08/02/16**
SOURCE OF BITUMEN	60/70 Pen. Grade	ASPHALT CONTENT	**4.4% - 5.6%**
TYPE OF MIX	TRIAL MIX DESIGN -- Hot Bin	SAMPLE REFERENCE	**20**

Calculation of Combined SG of Aggregate Mixture :

Maximum Size/ Bin No.	Bin #1 25 ~17	Bin # 2 17 ~10	Bin # 3 10 ~ 5	Bin # 4 5 ~ 3	Bin # 5 3 ~ 0	Stone Dust (Silos)	Mineral Filler	Weighted Average
Percentage Prop. (%) = P	**16**	**13**	**14**	**8**	**42**	**4**	**3**	
Bulk SG (oven dry) **Gsb**	2.890	2.872	2.856	2.789	2.761			**2.825**
Bulk SG (SSD) Gssd	**2.936**	**2.926**	**2.915**	**2.847**	**2.835**			**2.884**
Apparent SG (oven dry) **Gsa**	3.029	3.036	3.034	2.961	2.983	2.929	3.039	**3.002**
Water Absorption **(%)**	1.591	1.880	2.047	2.081	2.688			

Calculation of Maximum Theoretical Specific Gravity (G_{mm})

Gmm at 5.0% AC by Total mix	=	**2.647**
Gmm at 5.3% AC by Total mix	=	**2.643**
Specific gravity of Bitumen (AC), Gb	=	**1.026**

Calculation of Effective Specific Gravity of Aggregate (G_{se})

G_{se} at 5.0% Bitumen Content :

$$G_{se} = \frac{100 - P_b}{((100 / G_{mm}) - (P_b/G_b))} = 2.887$$

G_{se} at 5.3% Bitumen Content :

= **2.899**

Mean G_{se} = **2.893**

Calculation of Maximum Specific Gravity (G_{mm}) of mixes with different bitumen Contents

$$G_{mm} = \frac{100}{((P_s / G_{se}) + (P_b/G_b))}$$

Bitumen Content (%)	4.4	4.7	5.0	5.3	5.6
Bulk SG of Specimen (G_{mb})	2.495	2.522	2.529	2.547	2.550
Maximum SG of Loose mix (G_{mm})	**2.679**	**2.665**	**2.647**	**2.643**	**2.626**

EFFECT OF REHEATING AND REMOLDING

Aggregate Bin Source	**Hot Bin**	Aggregate Source :	**Quarry site at Ageremariam offset 8Km to Shakiso**
Trial Mix No.	**6**	Date of Testing	**8/2/2016**
Remark	**TRIAL MIX DESIGN**	Lab Ref.No.	**20**

Reheating Temperature		**0 time**			**5 hrs**			**12 hrs**			**24 hrs**			**48 hrs**		
% Asphalt		**5.25 %**			**5.25 %**			**5.25 %**			**5.25 %**			**5.25 %**		
Specimen Number		1.1	1.2	1.3	1.1	1.2	1.3	1.1	1.2	1.3	1.1	1.2	1.3	1.1	1.2	1.3
SPECIFIC GRAVITY																
A-wt. Of specimen in Air(dry)		1261.4	1262.3	1260.1	1262.8	1263.7	1262.4	1262.7	1261.9	1259.6	1261.5	1258.4	1272.6	1260.5	1259.4	1262.8
B-wt. Of specimen in Air(SSD)		1262.7	1263.9	1261.6	1264.7	1264.4	1264.0	1263.7	1263.2	1260.7	1262.9	1259.9	1273.3	1261.9	1260.9	1263.1
C-wt. Of spcimen in water		764.7	765.7	764.4	765.9	765.2	764.9	763.7	764.6	763.1	764.8	764.4	772.1	764.9	764.4	765.1
V-Volume of specimen	V=B-C	498.0	498.2	497.2	498.8	499.2	499.1	500.0	498.6	497.6	498.1	495.5	501.2	497.0	496.5	498.0
G_{sb}-Bulk Specific Gravity @25^{o}c	G_{mb}=A/V	2.533	2.534	2.534	2.532	2.531	2.529	2.525	2.531	2.531	2.533	2.540	2.539	2.536	2.537	2.536
Conversion Factor (k)	25 ^{o}C	1.00000	1.00000	1.00000	1.0000	1.0000	1.0000	1.00000	1.00000	1.00000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
G_{sb}-Bulk Specific Gravity @25^{o}c	G_{mb}=G_{mb}xk	2.533	2.534	2.534	2.532	2.531	2.529	2.525	2.531	2.531	2.533	2.540	2.539	2.536	2.537	2.536
G_{sb}- Avg.Bulk Sp. Gravity @25^{o}c			**2.534**			**2.531**			**2.529**			**2.537**			**2.536**	
G_{mm}-Max. Theoretical Sp. Grav.			**2.647**			**2.647**			**2.647**			**2.647**			**2.647**	
Voids																
Effective bitumen content (%)	P_{be}=P_b-(P_{ba}*P_s)/100		4.30			4.30			4.30			4.30			4.30	
V_a- % air voids	V_a=100x(G_{mm}-G_{sb})/G_{mm}	4.31	4.27	4.27	4.34	4.38	4.460	4.61	4.38	4.38	4.31	4.04	4.08	4.19	4.16	4.19
Average V_a-%Air void			**4.28**			**4.39**			**4.46**			**4.14**			**4.18**	
V_{ma}-% void in Mineral Agg.	V_{ma}=100-(G_{sb}*P_a/G_{sb})	15.0	15.0	15.0	15.1	15.1	15.2	15.3	15.1	15.1	15.0	14.8	14.8	14.9	14.9	14.9
Average V_{ma} (%)			**15.0**			**15.1**			**15.2**			**14.9**			**14.9**	
V_{fa}-% void Filled with Asphalt	V_{fa}=(V_{ma}-V_a)/V_{ma} x 100	71.3	71.5	71.5	71.3	71.0	70.7	69.9	71.0	71.0	71.3	72.7	72.4	71.9	72.1	71.9
Average V_{fa} (%)			**71.4**			**71.0**			**70.6**			**72.1**			**72.0**	
FLOW & STABILITY																
Height of the specimen -H	cm	62.13	62.24	62.05	62.01	62.12	62.18	62.20	62.13	62.14	62.26	62.51	62.18	62.76	62.10	62.12
Maximum Load	KN	11	10.4	9.74	10.3	11.2	10.45	9.87	10.89	10.5	11.25	9.88	10.1	11.3	10.12	9.9
Corrected Load (From Callibration Cert.)	e	14.22	13.45	12.59	13.32	14.48	13.51	12.76	14.08	13.58	14.55	12.77	13.06	14.61	13.09	12.80
Stability conversion factor	f	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
Corrected Stability	KN	14.79	13.99	13.09	13.85	15.06	14.05	13.27	14.64	14.12	15.13	13.28	13.58	15.19	13.61	13.31
Average Stability	KN		**13.96**			**14.32**			**14.01**			**14.00**			**14.04**	
Flow	mm	3.18	3.11	3.23	3.15	3.25	3.21	3.18	3.28	2.93	3.12	2.97	3.22	3.16	3.97	2.35
Average Flow	mm		**3.17**			**3.20**			**3.13**			**3.10**			**3.16**	
Ratio																

Apparent Specific Gravity of Aggregate Mixture	G_{sa}	=	**3.002**	
Effective Specific Gravity of Aggregate Mixture	G_{se}	=	**2.906**	
Bulk Specific Gravity of Aggregate Mixture (Oven Dry)	G_{sb}	=	**2.825**	
Specific gravity of Bitumen	G_b	=	1.01	
Number Of Compaction Blows		=	**75*2**	
Bitumen Type		=	**80/100**	
Temperature During Mixing		=	**150**	**^{o}C**
Temperature Mixture During Compaction		=	**145**	**^{o}C**
Bitumen Absorption	P_{ba}	=	1	%

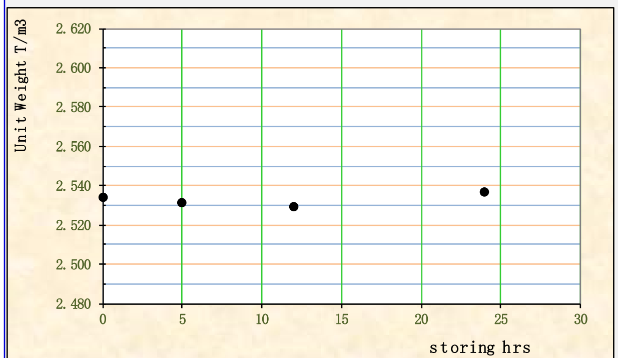
Conversion Factor k for various temperatures

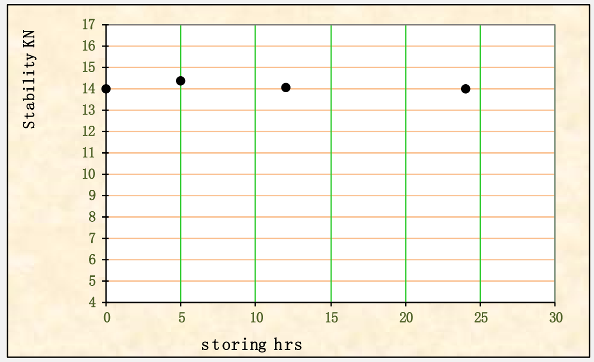
10^{o}c - 1.002661	17^{o}c - 1.001734	24^{o}c - 1.000253
11^{o}c - 1.002567	18^{o}c - 1.001555	25^{o}c - 1.000000
12^{o}c - 1.002458	19^{o}c - 1.001364	26^{o}c - 0.999738
13^{o}c - 1.002338	20^{o}c - 1.001162	27^{o}c - 0.999467
14^{o}c 1.002204	21^{o}c - 1.000950	28^{o}c - 0.999187
15^{o}c - 1.002060	22^{o}c - 1.000728	29^{o}c - 0.998898
16^{o}c - 1.001903	23^{o}c - 1.000495	30^{o}c - 0.998599

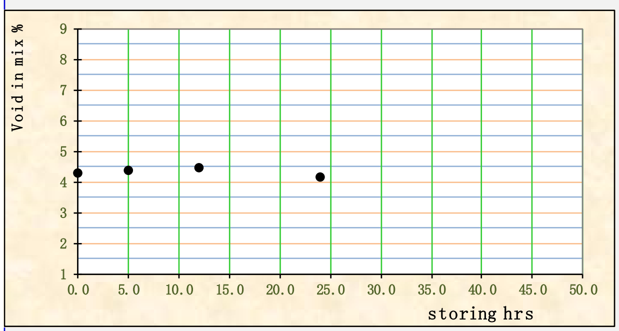
Source : Quarry site at Ageremariam offset 8Km to Shakiso

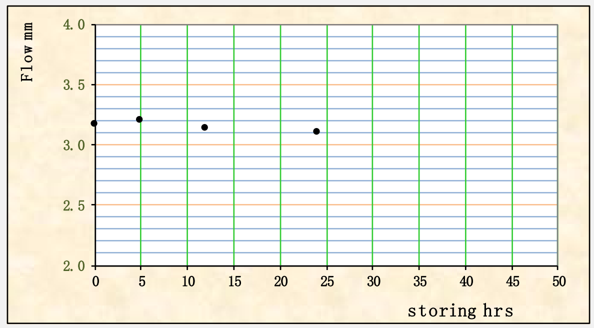
Asphalt Concrete Mix design - HMP-4

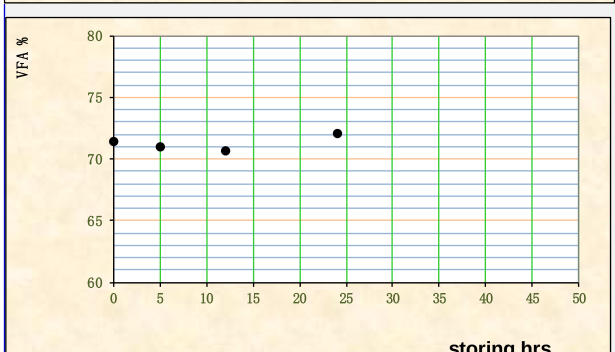
Asphalt 60/70 pen. Grade

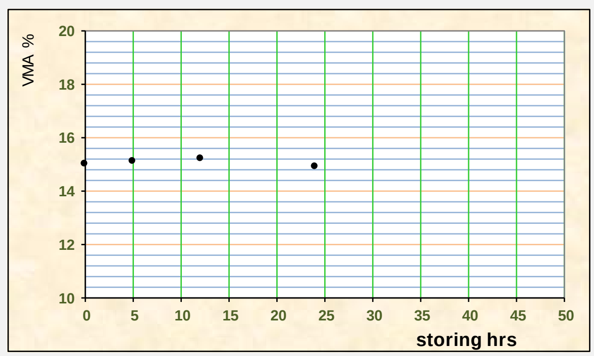










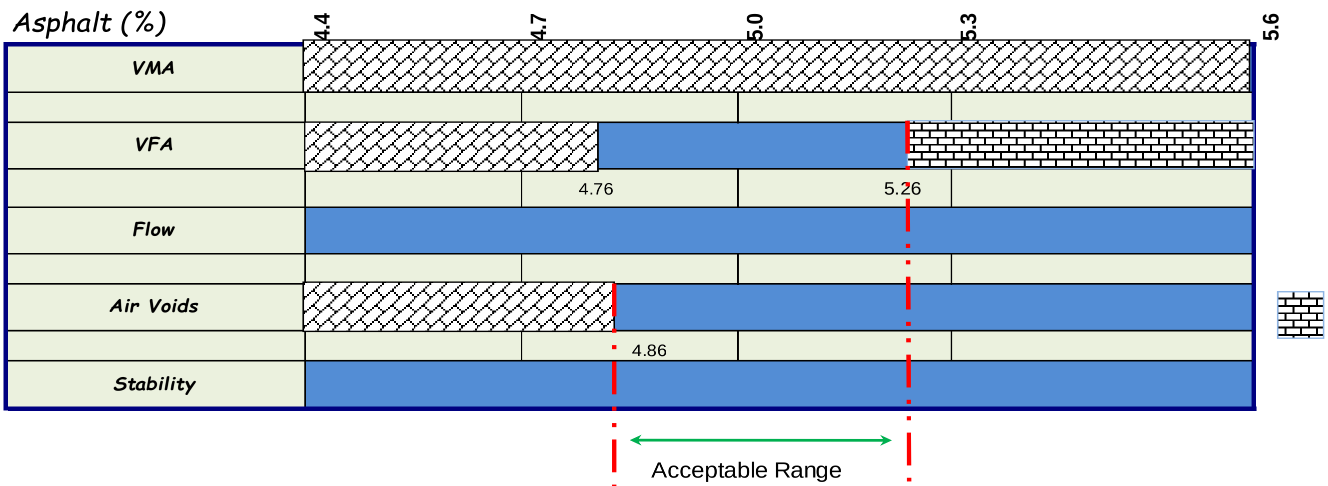


Target Asphalt Content		Result	Recommended Spcfication Limit 5 - 7
Stability at Target Asphalt Content	-Min. 4.40 %	12.02	Min. 9000 N
	-Max. 5.60 %	14.53	
Flow at Target Aspalt Content	-Min. 4.40 %	3.01	2 - 4 mm
	-Max. 5.60 %	3.27	
Air void at Target Aspalt Content	-Min. 4.40 %	3.63	3 - 5 %
	-Max. 5.60 %	6.870	
VFA at Target Aspalt Content	-Min. 4.40 %	55.9	65 - 75 %
	-Max. 5.60 %	80.7	
VMA at Target Aspalt Content	-Min. 4.40 %	14.6	Min. 13 %
	-Max. 5.60 %	15.6	

Source : Quarry site at Ageremariam offset 8Km to Shakiso

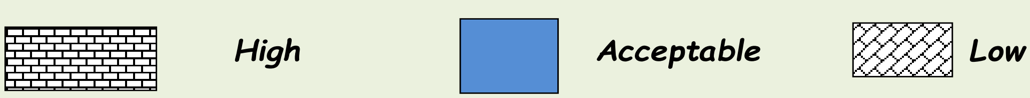
Asphalt 60/70 pen. Grade

Asphalt Concrete Mix design - HMP - 4



Remark The Target AC = 5.32% + or - 0.3

Legend



Appendix C

MARSHALL MIX DISGIN FOR ASPHALT CONCRETE WEARING COURSE (MARSHALL METHOD : AASHTO T-245)

Aggregate Bin Source	Hot Bin	Aggregate Source :	Quarry site at Ageremariam offset 8Km to Shakiso
Trial Mix No.	6	Date of Testing	8/2/2016
Remark	TRIAL MIX DESIGN	Lab Ref.No.	20

% Asphalt		4.40 %			4.70 %			5.00 %			5.30 %			5.60 %		
Specimen Number		1.1	1.2	1.3	1.1	1.2	1.3	1.1	1.2	1.3	1.1	1.2	1.3	1.1	1.2	1.3
SPECIFIC GRAVITY																
A-wt. Of specimen in Air(dry)		1253.2	1256.3	1256.0	1262.8	1256.7	1259.7	1262.7	1261.9	1259.6	1262.5	1259.4	1272.6	1262.9	1262.0	1262.5
B-wt. Of specimen in Air(SSD)		1255.6	1259.0	1259.0	1264.7	1258.4	1261.4	1263.7	1263.2	1260.7	1262.9	1259.9	1273.3	1263.7	1262.9	1263.3
C-wt. Of spcimen in water		751.8	756.7	755.9	762.9	761.2	761.6	763.7	764.6	763.1	767.8	765.4	773.1	767.3	768.9	768.5
V-Volume of specimen	V=B-C	503.8	502.3	503.1	501.8	497.2	499.8	500.0	498.6	497.6	495.1	494.5	500.2	496.4	494.0	494.8
G_{sb}-Bulk Specific Gravity @25^{o}c	G_{mb}=A/V	2.487	2.501	2.497	2.517	2.528	2.520	2.525	2.531	2.531	2.550	2.547	2.544	2.544	2.555	2.552
Conversion Factor (k)	25 ^{o}C	1.00000	1.00000	1.00000	1.0000	1.0000	1.0000	1.00000	1.00000	1.00000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
G_{sb}-Bulk Specific Gravity @25^{o}c	G_{mb}=G_{mb}xk	2.487	2.501	2.497	2.517	2.528	2.520	2.525	2.531	2.531	2.550	2.547	2.544	2.544	2.555	2.552
G_{sb}- Avg.Bulk Sp. Gravity @25^{o}c			**2.495**			**2.522**			**2.529**			**2.547**			**2.550**	
G_{mm}-Max. Theoretical Sp. Gra\			**2.679**			**2.665**			**2.647**			**2.643**			**2.626**	
Voids																
Effective bitumen content (%)	P_{be}=P_b-(P_{ba}*P_s)/100		3.59			3.89			4.19			4.50			4.80	
V_a- % air voids	V_a=100x(G_{mm}-G_{sb})/G_{mm}	7.17	6.64	6.79	5.55	5.14	5.440	4.61	4.38	4.38	3.52	3.63	3.75	3.12	2.70	2.82
Average V_a-%Air void	**Spec. (3-5 %)**		**6.87**			**5.38**			**4.46**			**3.63**			**2.88**	
V_{ma}-% void in Mineral Agg.	V_{ma}=100-(G_{sb}*P_a/G_{sb})	15.8	15.4	15.5	15.1	14.7	15.0	15.1	14.9	14.9	14.5	14.6	14.7	15.0	14.6	14.7
Average V_{ma} (%)	**Spec. (> 14 %)**		**15.6**			**14.9**			**15.0**			**14.6**			**14.8**	
V_{fa}-% void Filled with Asphalt	V_{fa}=(V_{ma}-V_a)/V_{ma} x 100	54.6	56.9	56.2	63.2	65.0	63.7	69.5	70.6	70.6	75.7	75.1	74.5	79.2	81.5	80.8
Average V_{fa} (%)	**Spec. (65 ~ 75 %)**		**55.9**			**64.0**			**70.2**			**75.1**			**80.5**	
FLOW & STABILITY																
Height of the specimen -H	cm	63.13	62.54	62.85	62.70	62.12	62.11	62.28	62.13	61.64	61.66	61.45	62.22	62.01	61.55	61.86
Maximum Load	KN	8.79	9.03	9.07	9.1	9.48	8.78	9.87	11.2	10.88	10.96	12.47	10.97	10.22	11.16	8.42
Corrected Load (From Callibration Cert.)	e	11.36	11.67	11.73	11.77	12.26	11.35	12.76	14.48	14.07	14.17	16.12	14.18	13.21	14.43	10.89
Stability conversion factor	f	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.09	1.09	1.04	1.04	1.09	1.09
Corrected Stability	KN	11.81	12.14	12.20	12.24	12.75	11.80	13.27	15.06	14.63	15.45	17.57	14.75	13.74	15.73	11.87
Average Stability	KN **Spec. (Min. 9 KN)**		**12.05**			**12.26**			**14.32**			**15.92**			**13.78**	
Flow	mm	2.48	2.71	3.83	3.03	3.55	2.91	2.68	3.68	2.83	3.32	2.97	3.52	2.90	3.63	2.92
Average Flow	mm **Spec.(2-4 mm)**		**3.01**			**3.16**			**3.06**			**3.27**			**3.15**	
Ratio																
Filler/Binder	**Spec.(0.6-1.2mm)**		0.68			0.64			0.60			0.57			0.54	

Apparent Specific Gravity of Aggregate Mixture	G_{sa}	=	3.002	
Effective Specific Gravity of Aggregate Mixture	G_{se}	=	2.893	
Bulk Specific Gravity of Aggregate Mixture (Oven Dry)	G_{sb}	=	2.825	
Specific gravity of Bitumen	G_b	=	1.0263	
Number Of Compaction Blows		=	75*2	
Bitumen Type		=	60/70	
Temperature During Mixing		=	150	^{o}C
Temperature Mixture During Compaction		=	145	^{o}C
Bitumen Absorption	P_{ba}	=	0.85	%

Filler Content (%) 3

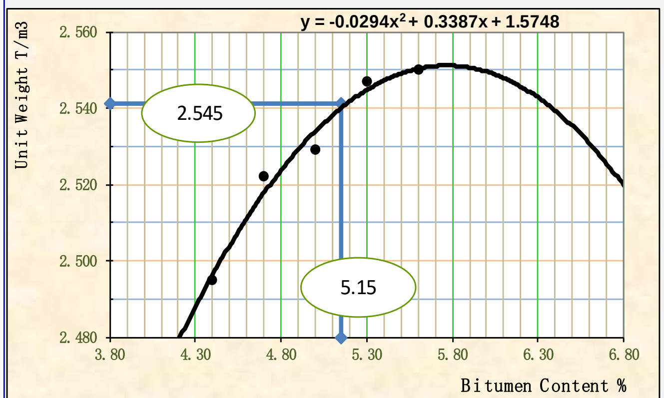
Conversion Factor k for various temperatures

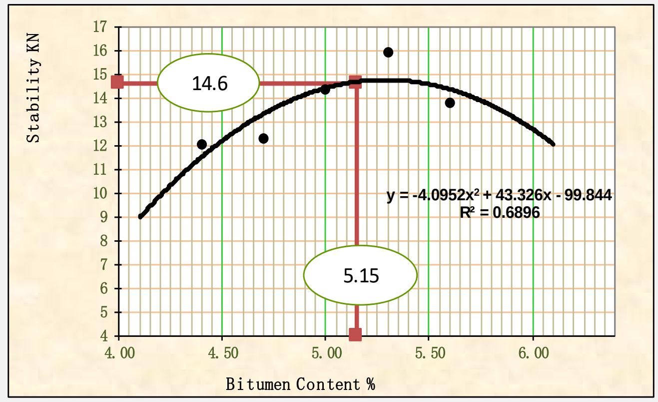
10^{o}c - 1.002661	17^{o}c - 1.001734	24^{o}c - 1.000253
11^{o}c - 1.002567	18^{o}c - 1.001555	25^{o}c - 1.000000
12^{o}c - 1.002458	19^{o}c - 1.001364	26^{o}c - 0.999738
13^{o}c - 1.002338	20^{o}c - 1.001162	27^{o}c - 0.999467
14^{o}c 1.002204	21^{o}c - 1.000950	28^{o}c - 0.999187
15^{o}c - 1.002060	22^{o}c - 1.000728	29^{o}c - 0.998898
16^{o}c - 1.001903	23^{o}c - 1.000495	30^{o}c - 0.998599

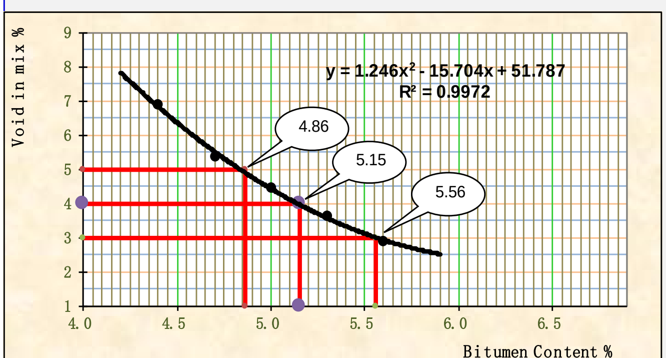
Source : Quarry site at Ageremariam offset 8Km to Shakiso

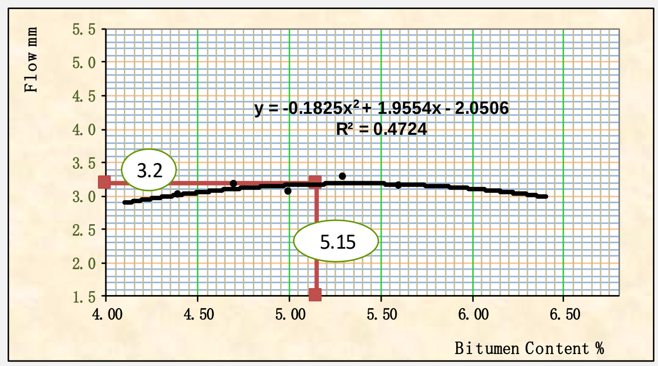
Asphalt Concrete Mix design - HMP-4

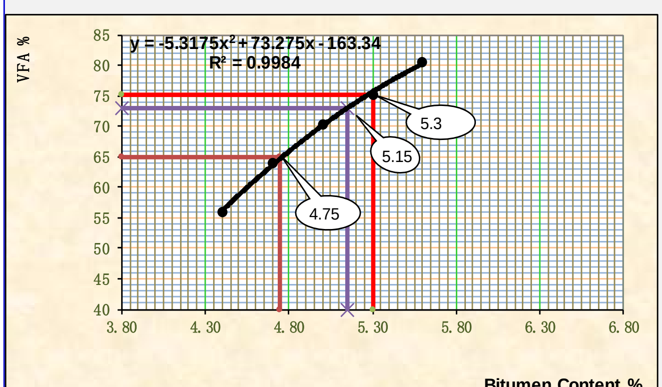
Asphalt 60/70 pen. Grade

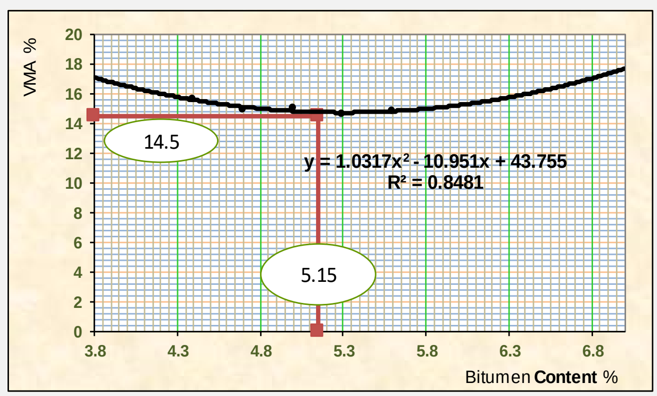










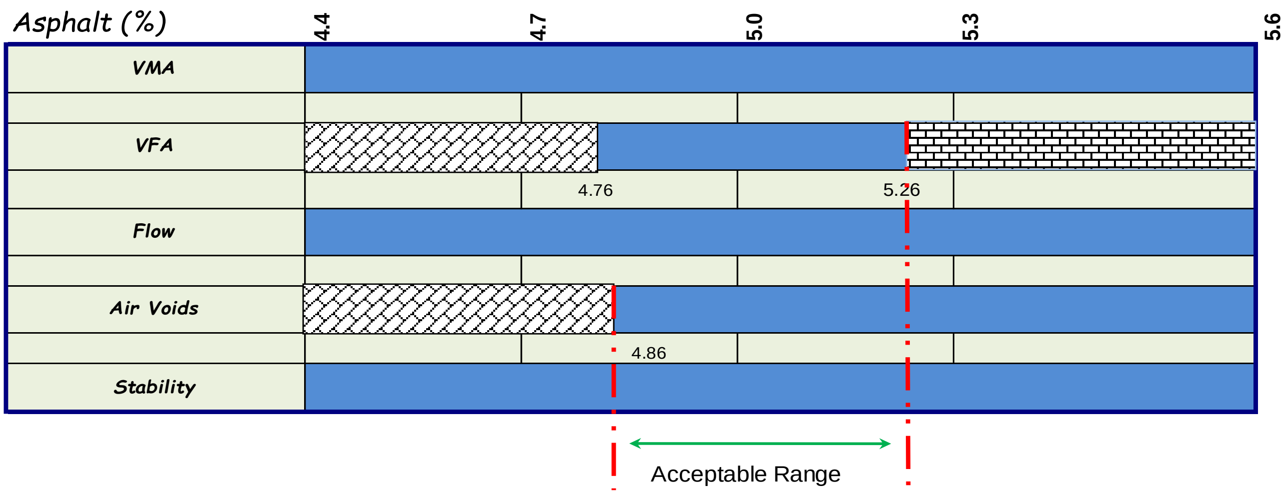


Target Asphalt Content			Spcfication Limit 5 - 7
Stability at Target Asphalt Content	-Min. 4.40 %	12.02	Min. 9000 N
	-Max. 5.60 %	14.53	
Flow at Target Aspalt Content	-Min. 4.40 %	3.01	2 - 4 mm
	-Max. 5.60 %	3.27	
Air void at Target Aspalt Content	-Min. 4.40 %	3.63	3 - 5 %
	-Max. 5.60 %	6.870	
VFA at Target Aspalt Content	-Min. 4.40 %	55.9	65 - 75 %
	-Max. 5.60 %	80.7	
VMA at Target Aspalt Content	-Min. 4.40 %	14.6	Min. 13 %
	-Max. 5.60 %	15.6	

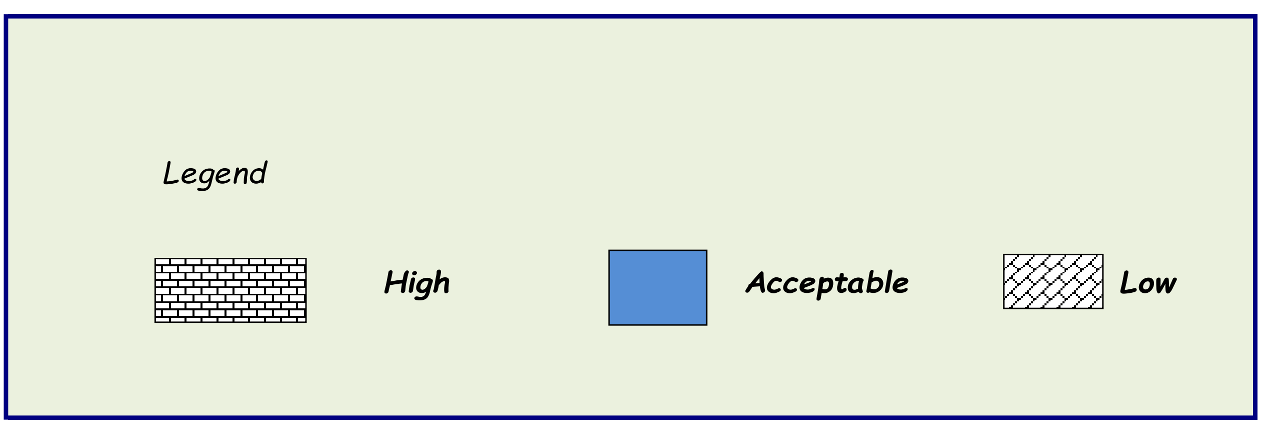
Source : Quarry site at Ageremariam offset 8Km to Shakiso

Asphalt 60/70 pen. Grade

Asphalt Concrete Mix design - HMP - 4



Remark



Appendix D

Compaction Temperatures at a different degree centigrade

Aggregate Bin Source	Hot Bin	Aggregate Source :	Quarry site at Ageremariam offset 8Km to Shakiso
Trial Mix No.	6	Date of Testing	8/2/2016
Remark	TRIAL MIX DESIGN	Lab Ref.No.	20

Reheating Temperature		60 °C		70 °C		80 °C		90 °C		100 °C	
% Asphalt		5.25		5.25		5.25		5.25		5.25	
Specimen Number		1.1	1.2	1.1	1.2	1.1	1.2	1.1	1.2	1.1	1.2
SPECIFIC GRAVITY											
A-wt. Of specimen in Air(dry)		1259.5	1260.4	1261.0	1262.4	1261.3	1260.7	1259.2	1257.2	1262.4	1260.4
B-wt. Of specimen in Air(SSD)		1264.6	1265.8	1265.9	1265.6	1264.6	1264.1	1263.1	1261.3	1263.6	1261.9
C-wt. Of spcimen in water		762.5	764.0	763.9	763.1	762.4	763.3	763.6	763.5	765.3	764.7
V-Volume of specimen	V=B-C	502.1	501.8	502.0	502.5	502.2	500.8	499.5	497.8	498.3	497.2
G_{sb}-Bulk Specific Gravity @25°c	G_{mb}=A/V	2.508	2.512	2.512	2.512	2.512	2.517	2.521	2.526	2.533	2.535
Conversion Factor (k)	25 °C	1.00000	1.00000	1.0000	1.0000	1.00000	1.00000	1.0000	1.0000	1.0000	1.0000
G_{sb}-Bulk Specific Gravity @25°c	G_{mb}=G_{mb}xk	2.508	2.512	2.512	2.512	2.512	2.517	2.521	2.526	2.533	2.535
G_{sb}- Avg.Bulk Sp. Gravity @25°c		2.510		2.512		2.515		2.524		2.534	
G_{mm}-Max. Theoretical Sp. Grav.		2.647		2.647		2.647		2.647		2.647	
Voids											
Effective bitumen content (%)	$P_{be}=P_b-(P_{ba}*P_s)/100$	4.37		4.37		4.37		4.37		4.37	
V_a- % air voids	$V_a=100x(G_{mm}-G_{sb})/G_{mm}$	5.25	5.10	5.10	5.10	5.10	4.91	4.76	4.57	4.31	4.23
Average V_a-%Air void		5.18		5.10		5.01		4.67		4.27	
V_{ma}-% void in Mineral Agg.	$V_{ma}=100-(G_{sb}*P_a/G_{sb})$	15.9	15.7	15.7	15.7	15.7	15.6	15.4	15.3	15.0	15.0
Average V_{ma} (%)		15.8		15.7		15.7		15.4		15.0	
V_{fa}-% void Filled with Asphalt	$V_{fa}=(V_{ma}-V_a)/V_{ma}$ x 100	67.0	67.5	67.5	67.5	67.5	68.5	69.1	70.1	71.3	71.8
Average V_{fa} (%)		67.3		67.5		68.0		69.6		71.6	
FLOW & STABILITY											
Height of the specimen -H	cm	63.13	63.24	63.01	63.12	63.30	63.10	63.40	63.30	62.80	62.65
Maximum Load	KN	6.7	5.2	6.2	7.1	7.1	6.9	7.5	8.1	8.6	9.8
Corrected Load (From Callibration Cert.)	e	8.66	6.72	8.01	9.18	9.18	8.92	9.70	10.47	11.12	12.67
Stability conversion factor	f	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
Corrected Stability	KN	9.01	6.99	8.33	9.55	9.55	9.28	10.09	10.89	11.56	13.18
Average Stability	KN	8.00		8.94		9.42		10.49		12.37	
Flow	mm	4.70	4.90	4.40	4.60	3.60	4.10	3.90	3.70	3.40	3.80
Average Flow	mm	4.80		4.50		3.85		3.80		3.60	
Ratio											

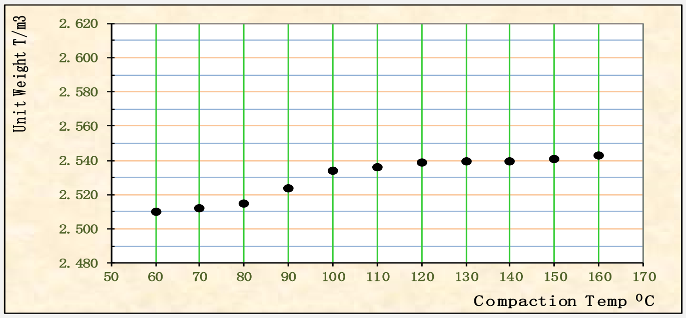
Reheating Temperature		110 °C		120 °C		130 °C		140 °C		150 °C		160 °C	
% Asphalt		5.25		5.25		5.25		5.25		5.25		5.25	
Specimen Number		1.1	1.2	1.1	1.2	1.1	1.2	1.1	1.2	1.1	1.2	1.1	1.2
SPECIFIC GRAVITY													
A-wt. Of specimen in Air(dry)		1259.5	1261.5	1258.7	1258.6	1261.6	1261.2	1260.4	1262.4	1259.0	1258.4	1260.1	1262.4
B-wt. Of specimen in Air(SSD)		1262.1	1262.9	1260.2	1260.8	1262.3	1262.0	1262.2	1263.2	1261.3	1259.9	1261.0	1261.9
C-wt. Of spcimen in water		765.0	765.8	764.8	764.5	765.6	765.4	765.5	766.4	765.8	764.4	765.3	765.4
V-Volume of specimen	V=B-C	497.1	497.1	495.4	496.3	496.7	496.6	496.7	496.8	495.5	495.5	495.7	496.5
G_{sb}-Bulk Specific Gravity @25°c	G_{mb}=A/V	2.534	2.538	2.541	2.536	2.540	2.540	2.538	2.541	2.541	2.540	2.542	2.543
Conversion Factor (k)	25 °C	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
G_{sb}-Bulk Specific Gravity @25°c	G_{mb}=G_{mb}xk	2.534	2.538	2.541	2.536	2.540	2.540	2.538	2.541	2.541	2.540	2.542	2.543
G_{sb}- Avg.Bulk Sp. Gravity @25°c		2.536		2.539		2.540		2.540		2.541		2.543	
G_{mm}-Max. Theoretical Sp. Grav.		2.647		2.647		2.647		2.647		2.647		2.647	
Voids													
Effective bitumen content (%)	$P_{be}=P_b-(P_{ba}*P_s)/100$	4.37		4.37		4.37		4.37		4.37		4.37	
V_a- % air voids	$V_a=100x(G_{mm}-G_{sb})/G_{mm}$	4.27	4.12	4.00	4.19	4.04	4.04	4.12	4.00	4.00	4.04	3.97	3.93
Average V_a-%Air void		4.20		4.10		4.04		4.06		4.02		3.95	
V_{ma}-% void in Mineral Agg.	$V_{ma}=100-(G_{sb}*P_a/G_{sb})$	15.0	14.9	14.8	14.9	14.8	14.8	14.9	14.8	14.8	14.8	14.7	14.7
Average V_{ma} (%)		15.0		14.9		14.8		14.9		14.8		14.7	
V_{fa}-% void Filled with Asphalt	$V_{fa}=(V_{ma}-V_a)/V_{ma}$ x 100	71.5	72.3	73.0	71.9	72.7	72.7	72.3	73.0	73.0	72.7	73.0	73.3
Average V_{fa} (%)		71.9		72.5		72.7		72.7		72.9		73.2	
FLOW & STABILITY													
Height of the specimen -H	cm	62.26	62.51	62.22	62.18	62.35	62.11	6.12	62.08	62.00	62.04	62.08	62.03
Maximum Load	KN	9.7	9.6	10.3	9.4	10.4	11.1	10.5	9.8	11.3	10.8	11.2	11.4
Corrected Load (From Callibration Cert.)	e	12.54	12.41	13.32	12.15	13.45	14.35	13.58	12.67	14.61	13.96	14.48	14.74
Stability conversion factor	f	1.04	1.04	1.09	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
Corrected Stability	KN	13.04	12.91	14.52	12.64	13.99	14.92	14.12	13.18	15.19	14.52	15.06	15.33
Average Stability	KN	12.98		13.58		14.46		13.65		14.86		15.20	
Flow	mm	3.40	2.60	3..1	2.90	2.40	2.50	2.60	2.40	3.30	3.10	3.60	3.10
Average Flow	mm	3.00		2.90		2.45		2.50		3.20		3.35	
Ratio													

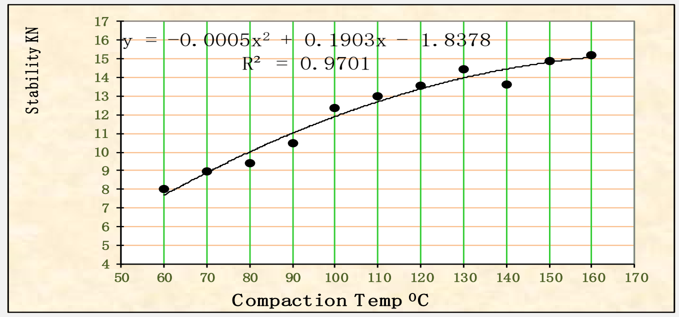
Apparent Specific Gravity of Aggregate Mixture	G_{sa}	3.002
Effective Specific Gravity of Aggregate Mixture	G_{se}	2.899
Bulk Specific Gravity of Aggregate Mixture (Oven Dry)	G_{sb}	2.825
Specific gravity of Bitumen	G_b	1.0263
Number Of Compaction Blows		75*2
Bitumen Type		60/70
Temperature During Mixing		150
Temperature Mixture During Compaction		from 60 to 160
Bitumen Absorption	P_{ba}	0.93

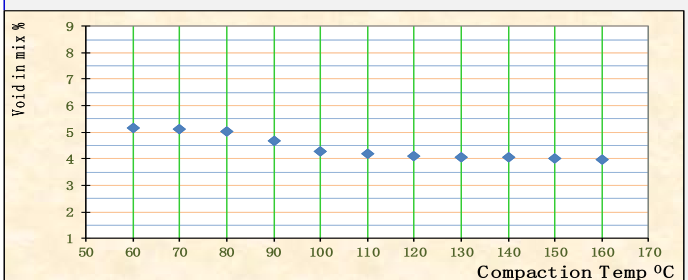
Source : Quarry site at Ageremariam offset 8Km to Shakiso

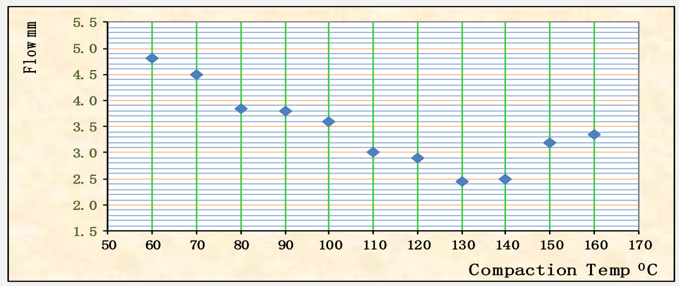
Asphalt Concrete Mix design - HMP-4

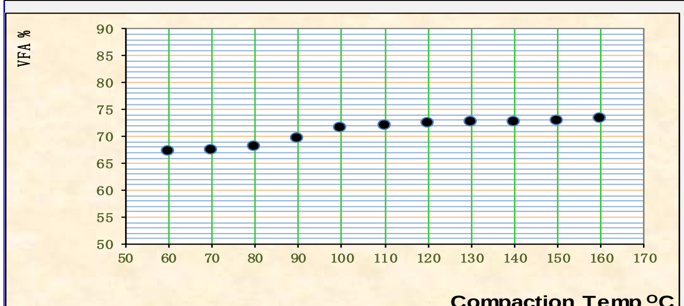
Asphalt 60/70 pen. Grade

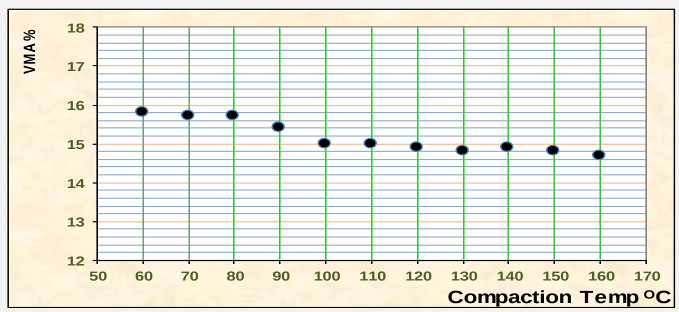












Target Asphalt Content		Result	recommended Spcfication Limit 5 - 7
Stability at Target Asphalt Content	-Min. 4.40 %	12.02	Min. 9000 N
	-Max. 5.60 %	14.53	
Flow at Target Aspalt Content	-Min. 4.40 %	3.01	2 - 4 mm
	-Max. 5.60 %	3.27	
Air void at Target Aspalt Content	-Min. 4.40 %	3.63	3 - 5 %
	-Max. 5.60 %	6.870	
VFA at Target Aspalt Content	-Min. 4.40 %	55.9	65 - 75 %
	-Max. 5.60 %	80.7	
VMA at Target Aspalt Content	-Min. 4.40 %	14.6	Min. 13 %
	-Max. 5.60 %	15.6	

Test Description	Compaction temperature at a different ^{o}C										
	60	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**
Balk Specific gravity	2.510	2.512	2.515	2.524	2.534	2.536	2.539	2.540	2.540	2.541	2.543
Via	5.18	5.10	5.01	4.67	4.27	4.20	4.10	4.04	4.06	4.02	3.95
VMA	15.8	15.7	15.7	15.4	15.0	15.0	14.9	14.8	14.9	14.8	14.7
VFA	67.3	67.5	68.0	69.6	71.6	71.9	72.5	72.7	72.7	72.9	73.2
Stability	8.00	8.94	9.42	10.49	12.37	12.98	13.58	14.46	13.65	14.86	15.20
Flow	4.80	4.50	3.85	3.80	3.60	3.00	2.90	2.45	2.50	3.20	3.35